EVALUATION AND COST COMPARISON OF ANTI-SILTATION SYSTEMS AND TRADITIONAL DREDGING METHODS

A PLAN B PAPER SUBMITTED TO
THE DEPARTMENT OF OCEAN AND RESOURCES ENGINEERING
OF
THE UNIVERSITY OF HAWAII
IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTERS OF SCIENCE
IN
OCEAN ENGINEERING

DECEMBER 2000

By

Victor V. Velasco

Committee

Kwok Fai Cheung, Chair
Hans-Jürgen Krock
Horst Brandes

ABSTRACT

Maintaining the design depth of ship servicing facilities is a challenging task. Dredging technology has improved significantly in the past few decades and this should have driven the cost downwards. However, increased environmental awareness has placed limitations on how dredge spoils are handled, transported and disposed of, and has effectively increased the costs of dredging operations. The United States Army Corps of Engineers and the Naval Facilities Engineering Command have conducted research into alternate sediment removal methods that may replace conventional dredging in sites where the conditions merit. The alternate systems include arrays of jets to prevent settling of suspended sediment and systems to entrain and transport sediment without physical removal. This study investigates the most promising techniques researched by the United States Army Corps of Engineers and the Naval Facilities Engineering Command for application at Naval Station Mayport, Florida. Naval Station Mayport has a long history of high sedimentation rates and difficulty in maintaining design depths at the piers, despite several studies to determine cost effective alternatives. Although several conservative assumptions were made concerning environmental conditions at the site that directly affect the design concept presented, the economic analysis indicated substantial saving can be realized if an alternate system consisting of turbo scouring units and a catchment basin were installed. The analysis takes into consideration the initial capital cost and the annual operation and maintenance of the alternate system for a 30-year life cycle, adjusted for inflation and compares the total cost against the cost to continue the current dredging operations at the existing frequency and quantities.

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1. INTRODUCTION

The last century has seen technology develop in great strides. Manufacturing processes are becoming more efficient and the demand for goods is increasing along with the growth of the human population. Through all this, shipping has remained a prime method for transporting goods and people. A solution for providing the increased amount of consumer products and the associated raw materials has been to increase the size of cargo ships. This provides a means to transport more goods in fewer trips. A drawback to the increased capacity of vessels is their deeper drafts. Navigational channels, harbor facilities and port equipment have to be expanded to handle the larger ships; otherwise the vessels will have to dock at other locations. Figure 1 shows a vessel with a draft of over 20 meters. Supporting deep draft vessels has become a major factor in the economic success of a city, to the point where municipal funds in millions of dollars are being committed to capital improvements and maintenance of new support facilities.

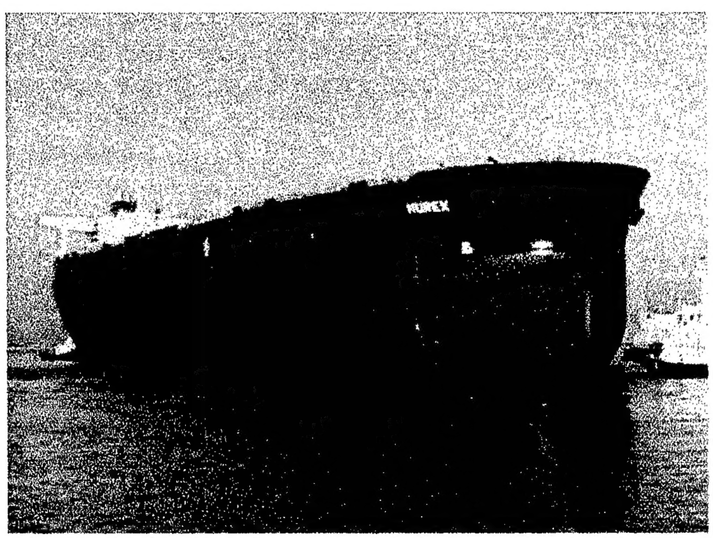


Figure 1. Very Large Crude Carrier (VLCC)

Maintaining design depths against the natural processes of sedimentation has long been a concern of harbor officials. Dredging by physically removing built up sediment on a periodic basis has long been the standard practice for maintaining a specified depth. Technology has improved the efficiency, and speed of the dredging process has also increased, but the cost of dredging has increased as well. Issues such as finding a suitable location to dispose of the dredge spoils, whether or not the sediment is contaminated with pollutants, the size of the particles and the potential for turbidity production during the dredging operation also contribute to the cost of dredging. Disposing dredging spoils is an issue that is usually determined by environmental regulations. The options are usually placement in an upland facility for reclamation or holding, placement on coastline areas for nourishment or offshore disposal. Particle size restrictions and contaminant level tests are used to ensure offshore disposal will not harm the ecology of the disposal sites. Agricultural use, land reclamation and beach nourishment are a few of the ways dredge spoils can be used, provided the sediment is not contaminated. If there are unacceptable levels of contamination present in the dredge material, contained disposal becomes mandatory. In any case, the cost of disposal is additive to the cost of dredging.

Dredging without first considering the possible effects to the sediment budget and the surrounding environment can also create new issues. A common problem associated with dredging in a littoral cell is the loss of upstream sand deposits. Without a supply of sand upstream, beaches downstream of a longshore current will be eroded. Turbidity fallout can smother reef developments or other benthic environments. Deepening harbors can also radically affect estuaries and wetland configurations. It is apparent, in light of the current legislature on environmental protection, that reliance on existing harbor

facilities will be the most feasible option for shipping requirements in opposition to creating new facilities.

Traditional dredging processes take sediment from the bottom by sucking, lifting or scooping. The dredging equipment is usually mounted on a barge or a vessel and has to be positioned above the area to be dredged. Clamshell, trailing suction hopper, hydraulic backhoe, and cutter suction dredges are some of the typical pieces of dredging equipment commonly used today (Bray et al. 1997). Additional tools, such as cutter heads shown in Figure 2, can be used to breakup layers that have consolidated or are composed of hard material. The technology used in dredging has improved in recent years, which should have decreased the cost of dredging operations. However, the issues of pollution control, disposal, environmental protection and other concerns are driving the costs higher.

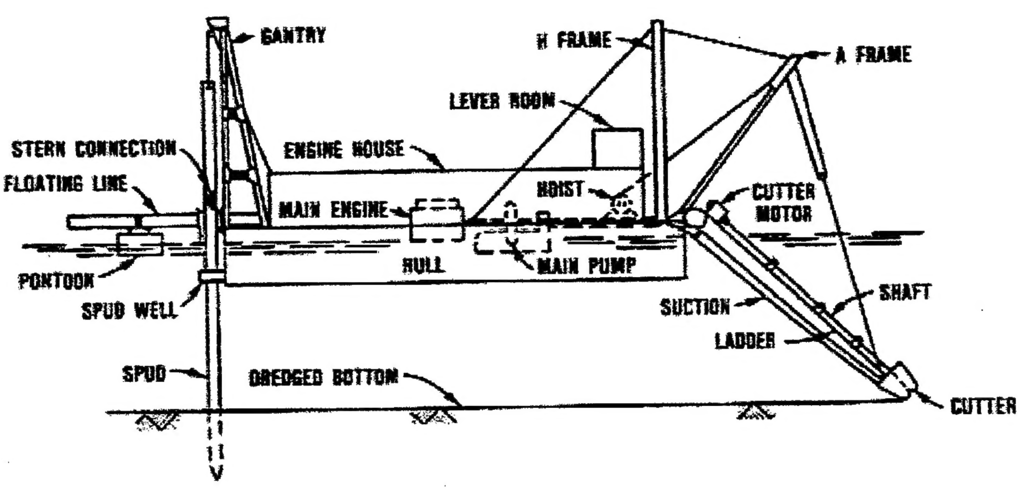


Figure 2. Cutterhead Dredger

Alternative methods for maintain berthing and channel depths have existed for several years, and are currently in use in Europe and other regions. Only recently, because of increasing costs and stringent environmental regulations, has their use in the United States been seriously considered. The Army Corps of Engineers has researched several alternative channel-dredging techniques through the Dredging Operations Technical Support Program (www.wes.army.mil/el/dots/doer/pdf/trdoer5.pdf). The techniques rely on entraining sediment into the ambient current or within bed-load layer to transport the sediment downstream of the site in question. Other methods use fluidization of sediment to assist in pumping the mixture through a pipeline to an alternate location. The Naval Facilities Engineering Command has also conducted research into techniques for use specifically at ship berths (Hoffman, 1980).

The high shoaling rates experienced at several harbor facilities that the U.S. Navy uses are a cause for concern. The projected, increasing cost of dredging will become a financial burden in the maintenance budgets of these facilities supported directly through federal allocations. Periodically reviewing the recent developments emerging from the dredging community is prudent in ensuring the best use of government funding. Should alternative dredging systems prove to be a more effective and efficient method to maintain design depths, their use where applicable should be pursued. The focus of this paper is the applicability of fluidization techniques, and the economic feasibility of their use in place of conventional dredging. This paper reviews the mechanisms of sedimentation and the alternate sediment removal methods that have been tested in the past few decades. The characteristics of the United States Naval Station at Mayport, Florida is provided and the best configuration of alternate sediment removal methods is

recommended based on suitability. An economic analysis is provided to determine if conventional dredging or the installation of an alternate system is the most economically feasible options over a time span of 30 years. Finally the predicted environmental impact that the proposed alternate system would have on the basin and the immediate surrounding area is also discussed.

2. SEDIMENTATION PROCESSES

2.1 Sediment Generation

Understanding sediment behavior is the first step to successfully determining a suitable method for maintaining design depths in a harbor. Sediment transport is an intrinsic part of continental evolution and is intimately connected to the water cycle. Figure 3 provides a schematic sketch of the rock cycle (Das, 1998) and shows how all forms of rock are subjected to erosion, weathering and transportation. The fallen rainwater erodes or reacts chemically with exposed rock to create weathered particles. Watersheds originating in elevated regions collect precipitation and focus streams into rivers. As the river and the associated tributaries flow to the sea, loose particles along the way are entrained into the flow. The entrained particles themselves scour more resistant forms of geology along the flow path. The sediment eventually is carried to the sea where it settles without the influence of fast river currents (Allen et al. 1990).

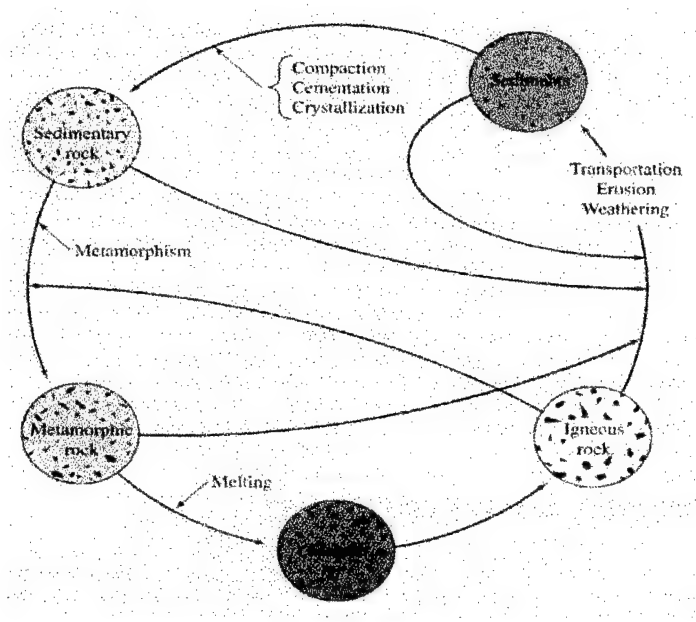


Figure 3. Rock Cycle (Das, 1998).

The fine sediments that collect on the vast abyssal plains are eventually subducted underneath continental shelves into the mantle or thrusted upwards against another tectonic plate. The subducted material is liquefied and eventually resurfaces as basalt or other igneous forms, while the sediments undergo other processes, such as compaction, cementation, crystallization and metamorphism to form sedimentary or metamorphic rocks. Through this process, the original sediment particle is recreated as solid rock to begin the cycle again.

2.2 Sediment Settling

Oceanic abyssal plains have large quantities of fine sediment carried out to sea by river currents and wind sources. Entrained sediment settles out when the upward turbulence in the flow can no longer support it against the pull of gravity (Chien, 1998). Where rivers flow into large, relatively calm bodies of water, such as bays, lakes, harbors, reservoirs or the open ocean, the flow velocity decreases. If the residence time of the sediment-laden water is sufficiently long, the particles will settle and come to rest on the bottom. Over time, the built-up sediments consolidate, fill-in the body of water and divert the flow. Estuaries and wetlands trap sediments as the water flows through the plant rich coastal plain. Neither the river currents nor the wind is capable of carrying coarser particles over large distance beyond the abyssal plains. Coarser particles are transported along continental shelves by coastal longshore currents, underwater sediment slides and the effects of typhoons and hurricanes which can sweep sediment offshore through severe wave action, increased storm water levels and strong currents.

In a quiescent fluid, a sediment particle resists the force of gravity by its displacement and the amount of drag its shape induces. At the onset of falling, the force of gravity is greater than the resistance and the particle undergoes acceleration. After a certain time, if the fall distance is not limited, the resistance to motion increases and becomes equal to the force of gravity acting on the submerged particle. At this point the particle falls at a constant velocity for a given fluid. The surrounding fluid is influenced and moved by the falling particle. The Reynolds number relates the inertial force to the viscous force of the fluid. At lower Reynolds numbers, the inertial forces have less influence than the viscous forces and the resulting flow regime is laminar. For a spherical shaped particle falling in the laminar region, the fall velocity is proportional to the square of the sphere diameter. Stoke's Law is also pertinent in discussions of particle fall velocity. Increasing the Reynolds number sees an increase in the significance of the inertial force and a decrease in the effect of the viscous force. With the increase in inertial force effects, flow around the sediment particle begins to separate from the body and wakes and vortices are formed. Transitional flow, around spheres falling through water at standard temperature and pressure, is seen between Re values of 0.4 and 1000. Turbulent flow develops when Re > 1000, the viscous force becomes negligible and the fall velocity is linearly proportional to the square root of its diameter.

This forms the basis of describing sediment settling in a quiescent fluid. Other factors such as the shape of the particle (theory is based on spherical shapes – actual conditions vary widely), the presence of a boundary (bottom and sides of a channel), the concentration of sediment in the flow, the grading of the entrained sediment particles, the

presence of turbulence, interaction with the surrounding fluid, and whether or not the particles have flocculated all affect the fall velocity of sediment.

2.3 Sediment Transport

Currents in bodies of water transport sediment. The fluid velocity, if increased over a range, will eventually reach a threshold value where the individual sediment particles begin to move. The shear stress imposed by the moving fluid is capable of inducing two types of motion – bed load and suspended load. Bed load describes the sliding, rolling or saltation motion that the particles take on as the critical threshold velocity is exceeded. With further increase in the fluid velocity, the particles will become entrained or suspended in the flow. With a well-graded particle distribution, smaller particles will begin to move in slower current before larger particles. The interaction between the moving fluid and the bedform will also determine the induced motion of the particles. Under a steady state fluid flow, equilibrium between the particles being suspended and falling out of suspension will be reached, for a given velocity and particle size distribution. These principles take on a new dimension of complexity when a real world situation is looked at.

In actual estuaries, the behavior of sediment is very different than the laboratory observations. Processes such as flocculation, deposition, consolidation and re-erosion affect how sediment is transported and there are several detailed studies outlining how these processes work individually (e.g., National Academy Press, 1987). However, the interactions they have together differ with the conditions present in each river and with daily weather fluctuations, together offering infinite possibilities. However, for the

purposes of simplicity and due to the lack of actual data on bottom sediment particle size and characteristics, assumptions will be made concerning sediment behavior. These assumptions are discussed in the subsequent sections describing the specific site characteristics.

Several forces drive fluid motion in open water (Garrison, 1999). Winds blowing over the surface of water generate waves and current in the direction of the winds. Density currents (salinity and temperature) that affect circulation across the globe are generated along the tropics and reinforced in the Polar Regions. Bathymetric features have an effect on how currents flow within an area. In a localized area, currents can have different properties at different depths. The surface is more likely to be affected by the wind and tidal forces. Along the bottom, the contours and prominent features influence how water flows. At intermediate depths, mixing between layers and the influence of other currents determine the course. Understanding the current structure in a localized area where sedimentation is being studied is of paramount importance. Knowledge of what type of sediment is present and how the sediment enters an area can lead to identifying the most appropriate way of dredging the material.

When a force is imparted onto a fluid body, such as a moving slug of water entering a stationary body of water, the impulse is received by as a change in momentum. Under the influence of an opposing force, the flow rate of a fluid body will change and the fluid momentum will eventually decay to zero. Applying this to sediment entrained water, if the flow reaches an area where the velocity can decrease, the particles will eventually settle out of suspension. The flow structure will also deform under the application of a

force. Shearing and resistance to motion due to boundary effects play an important part in sediment loading throughout the water column. This factor is discussed further in the effective ranges of scouring systems.

2.4 Sedimentation in Harbors and Estuaries

In general, the sediment load of a harbor or shipping channel can be attributed to two main sources: longshore transport deposits driven by wave action and currents, and deposition from rivers and tidal effects. The longshore transport carries sediment parallel to the coastline. Beaches are nourished or choked depending on the amount of sediment they receive from this mechanism. In areas where there are few natural harbors, man-made harbors and channels have been constructed to allow commercial shipping and recreational boating. Examples of this type of facility are the Dana Point Harbor and the Port of Los Angeles, both in Southern California. Over time these facilities are filled in primarily by the longshore transport of sand and coarser grained material.

Other typical areas used for shipping purposes are natural bays and estuaries that have been cut by the action of rivers. The shipping facilities are typically located at the river mouths or inland along the rivers. Examples of this type of facility are the facilities inside Chesapeake Bay, Virginia, the facilities at Puget Sound in Washington, and the facilities inside of San Francisco Bay, California. The same rivers that created the natural harbors are continuously at work to fill them in. The sediments carried downstream in the rivers are predominantly fine silts and clays. When these particles contact saltwater, their charged surfaces begin to interact with the ions present in solution. Flocculation

occurs and the sediments fall with a faster velocity because of their greater collective submerged weight.

Examining the rivers where there are large sediment loads, the areas subjected to saltwater exposure can be identified by the presence of wetlands and estuaries containing saltwater resistance plants. These plants (mangroves and reeds) grow in the built up sediments and provide a sediment trap with their stalks and root systems by slowing the velocity of the flowing water. As sediments settle, the layers begin to consolidate and their behavior changes from that of a loose fluff to a more permanent, stiffer material with the loss of water content. Over time, this process builds up regions and changes the course of rivers. Particles that are not captured in the estuaries are either taken out to sea, settle along the bottom of the river, or if the conditions permit, flow into an area of calmer water. The same settling process happens to the sediment regardless of its ultimate destination, but in harbors and bays used by man, the effects result in loss of facility use and subsequent maintenance dredging activities. The greater the residence time that the water has in the basin, the more likely the sediment will settle on the bottom.

The sediment particles cycle through several processes under the influence of currents and tidal forces as they pass through an estuary. Flocculation, sedimentation, deposition, consolidation and re-erosion are possible processes that the sediment might go through during a tidal cycle. These are crucial elements if the cycle is going to be modeled numerically. A schematic representation of the various cycles of sediment settling and erosion in an estuary is presented in Figure 4. During spring tides, the current velocities

are greater due to the higher elevation gradients. It is expected that greater amounts of erosion will occur and greater concentrations of suspended sediment will be observed. During neap tides, the opposite is expected – greater settling and consolidation, less erosion occurring due to the slower currents (Pye, 1994).

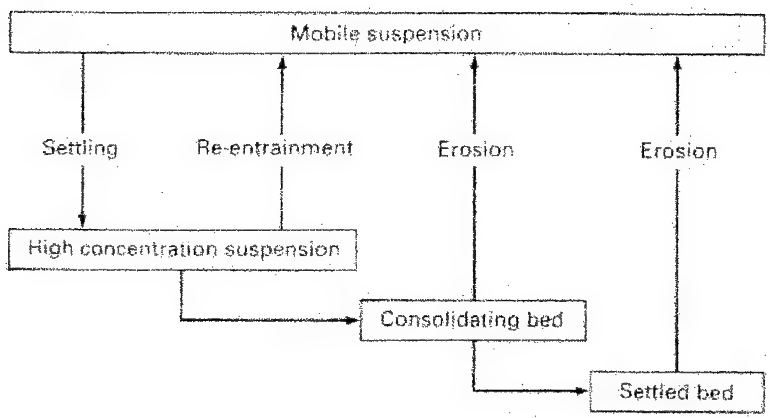


Figure 4. Estuary Sediment Cycle (Pye, 1994)

Sediment behavior is very complex and the effect each process has on the other processes is difficult to isolate. In estuaries, the sediment grain sizes are relatively small, ranging from fine sand to clay particles. Unlike granular sand, the shear stress required to entrain particles of this size and nature is not easily quantifiable. Uniformly distributed, unconsolidated diatomaceous earth was shown to have a shear stress of 0.1 N/m^2, a flow achievable with a small pump (Dellaripa et al. 1986). Considering the wide range of sediment types and sizes present in estuaries; this value for shearing stress should be regarded as a low-end, unconservative value. When the sediment consists of a wide

particle size distribution, from coarse silt to fine clay, the threshold velocity was found to range from 0.18 N/m^2 to 1.1 N/m^2 (Mehta et al. 1975).

Settling time is considerably different between an individual particle and a flocculated group of particles. There is uncertainty in how the clay-sized particles will group together as they flocculate in real world conditions. This introduces the problem of what particle size needs to be analyzed with respect to entraining the settled particles. For the purposes of this study, the sediment load will be considered to be a layer of mud, composed of flocculated particles that has recently settled, but that has not yet had time to consolidate.

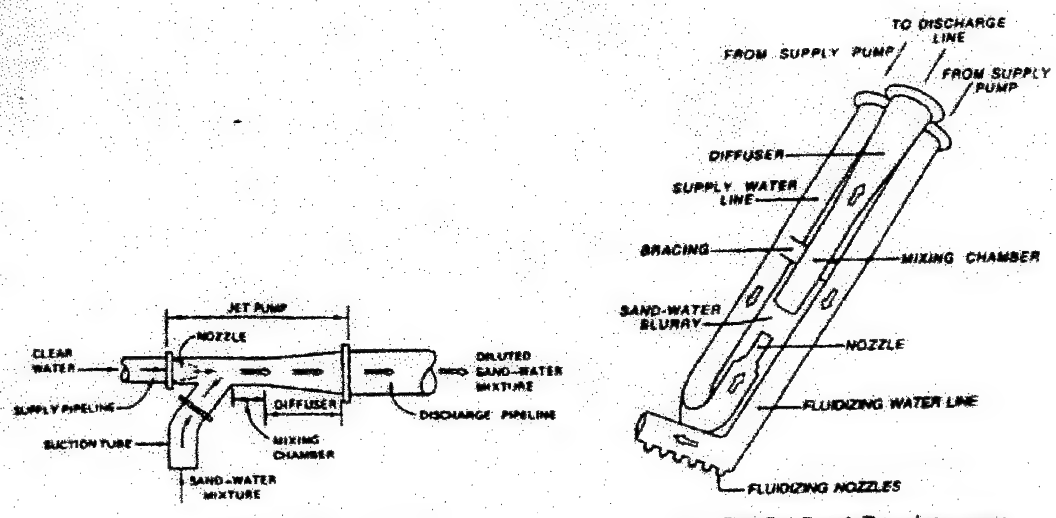
3. ALTERNATE SEDIMENT REMOVAL SYSTEMS

3.1 Overview

Using the principles discussed in the previous chapter, the shear stress required to entrain sediment particles can be calculated. The sediment travel distance must also be considered. The energy placed into the sediment must keep it suspended until the particles travel away from the area of concern or to a point where natural currents carry them away. Using water jets to impart a velocity is one way to deliver the shear stress required to entrain sediment from a bed. If sequenced properly, the water jets will also generate a current that will transport the entrained particles away from the site and into a stronger, more permanent flow such as a river.

Water jets are used in several different applications throughout industry. High-pressure streams mixed with fine aggregate are used to make high precision cuts through several inches of solid metal. Filtration through aggregate beds is rapidly becoming a preferred method of clarifying treated wastewater for particulate remnants. The U.S. Navy operated wastewater treatment plant at Fort Kamehameha, Oahu, Hawaii utilizes a bed of anthracite to trap the particles that remain in the effluent flow after treatment in secondary clarifiers. To clean the filter bed media, a rail mounted water jet head is passed over the filter. As the head passes over the filter, the water jet penetrates and temporarily fluidizes the bed. The trapped particles are entrained and returned to the secondary settling tanks for further processing. Mining is another process that uses water jets. The water jet is used to cut through the bulk material, usually softer material, and simultaneously fluidizes it for transport through a pipeline or open trough. Due to

harmful environmental impacts because of improper use, this mining technique has slowly been ceased. Underwater cable plows used for laying fiber optic transmission lines are equipped with water jets along the leading edge of the plow to reduce the lateral load required to cut the trench through the sediment. With respect to conventional dredging operations, water jets are being used in cutting heads to assist in breaking up sediment layers before they are sucked up through the dredging lifts (see Figure 5). Alternative dredging methods use water jets quite extensively. Techniques such as Water Injection Dredging (WID), Linear Jet Nozzle Arrays, Scouring Jet Arrays, Turbo Scouring Units, and Bypassing Systems all utilize jet pumps to move sediments.



a. Schematic of a simple jet pump

b. Genflo Sand Bug jet pump used in the Nerang River Bypassing System

Figure 5. Jet Pump Examples

3.2 Water Injection Dredging

Water Injection Dredging (WID) has been in use in Europe since the 1980's. Figure 6 shows a WID operating in a harbor. The European company HAM Holland holds the patent on WID, and the Ministry of Transportation in the Netherlands has accepted the water injection dredging process for use in Danish ports (www.hamdredging.com/techniques/wid.htm). Gulf Coast Trailing Company is a WID license holder here in the United States. The pumps and equipment are mounted on barges that can be mobilized relatively quickly because position-stabilizing equipment commonly found on conventional dredging rigs are not required. The technique is based on injecting water at low pressure through a nozzle-equipped arm into the sediment bed directly below the dredge. The process produces a fluidized layer that is denser that the water surrounding it and in the presence of a current, such as a river, or an elevation gradient, the layer will flow.

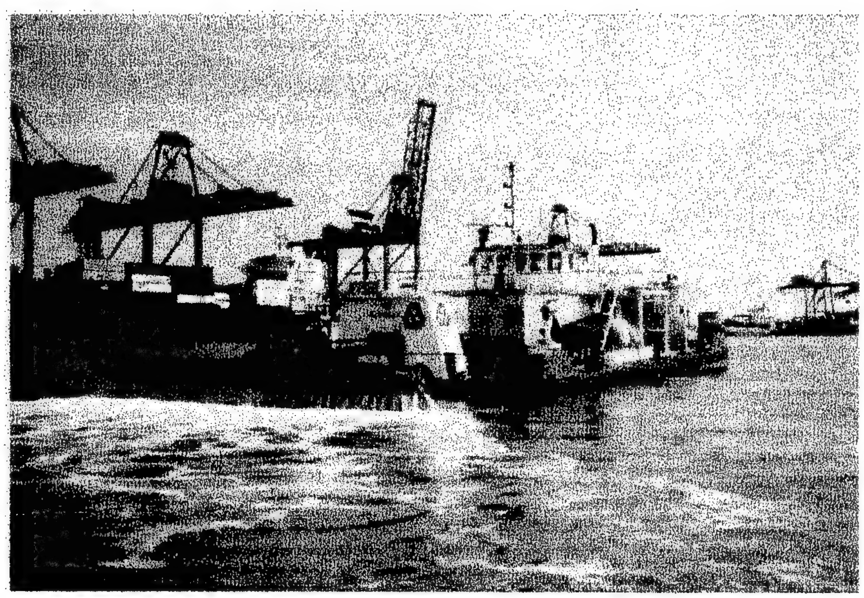


Figure 6. Water Injection Dredge

The Army Corps of Engineers conducted WID tests at two sites along the Mississippi River in 1992: Lower Zumbro in Minnesota/Wisconsin and Savanna in Illinois/Iowa. The tests were conducted using the BT-208 non-self propelled barge. The barge is 87 feet by 28 feet and draws a 3-foot draft. A similar unit is shown in Figure 7. The results showed that the predicted performance was met within reasonable allowances (Sardinas and Krumholz, 1993). The density current remained isolated and close to the bottom, and movement of particles smaller than 0.18 mm was achieved according to predicted production rate of 250 cu yd/hr at the Lower Zumbro site. An actual production rate of 350 cu yd/hr was achieved at the Savanna site versus the predicted 450 cu yd/hr rate. Turbidity downstream of the sites was recorded at 2 feet below the surface and 2 feet above the bottom. The reported levels were under the turbidity standards of 25 nephelometric turbidity units (NTUs), and were generally at background levels or less than 10 NTUs above background.

Additional tests in lower Louisiana yielded similar results (Williams, 1994). Gulf Coast Trailing conducted the water injection dredging using the same equipment from the 1992 tests. The area dredged was the Calumet floodgates in Bayou Teche, Louisiana. The total amount of production was 21,995 cubic yards, all dredged within 2 calendar days. The total cost for the dredging was $49,098, of which $15,000 was paid for mobilization. This cost was significantly lower than the $85,000 government estimate for bucket dredging. The estimated time frame for the bucket dredge operation was two to three weeks. The conditions in this project were ideal for the WID. The Wax Lake Outlet, which drains the East and West Calumet floodgates, has a design depth of 80 feet mean low gulf (MLG), while the floodgate channels were dredged to 9 feet MLG. The gradient

between the starting and ending points, as well as the presence of the Wax Lake Outlet current allowed the WID to accomplish the amount of dredging in such a short time frame. The three-person crew and the faster mobilization/demobilization times also contributed to the lower costs.

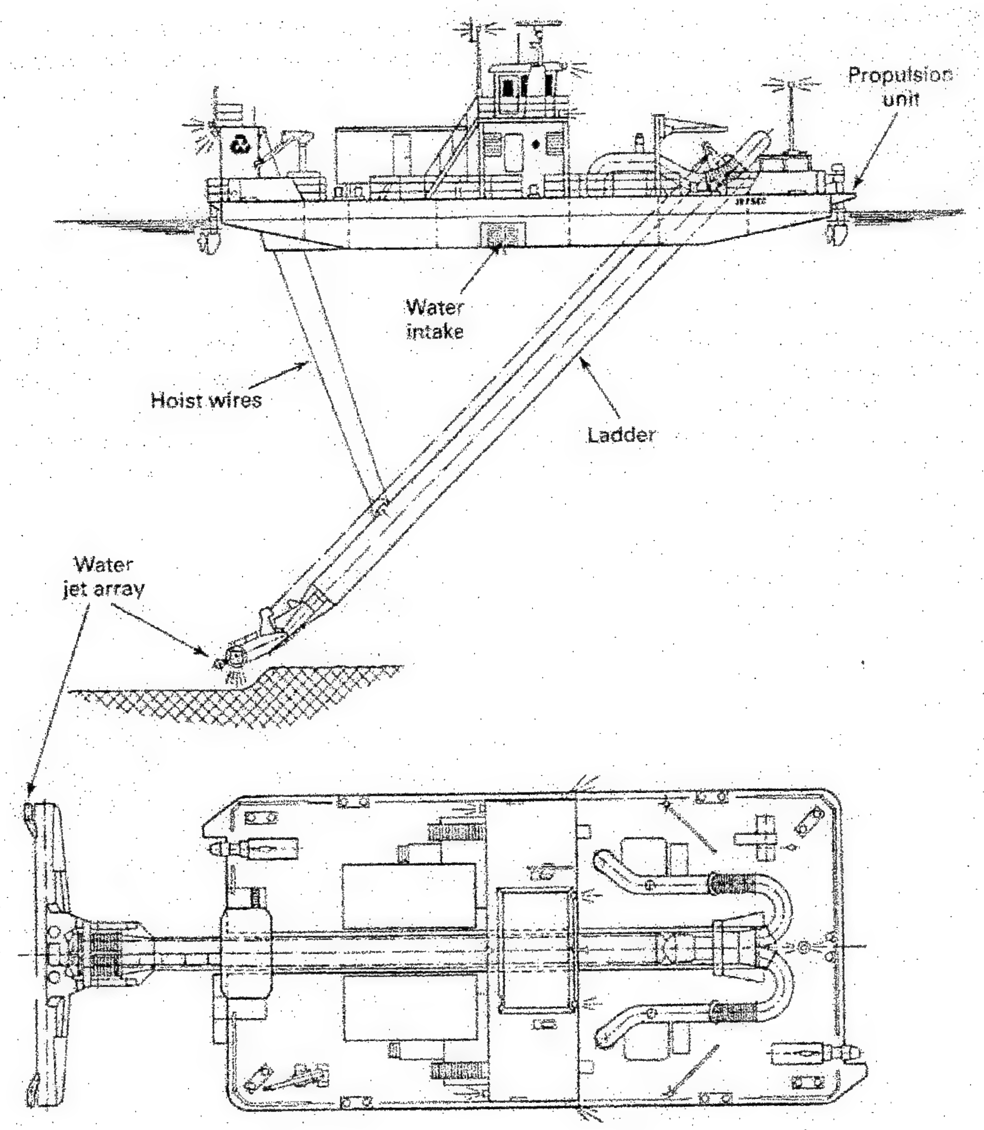


Figure 7. Water Injection Dredge Schematic

Water injection dredging is also a desirable process in areas where conventional dredging techniques could damage cables, pipelines or other pieces of underwater equipment. The Magnetic Silencing Facility at the U.S. Navy Submarine Base at Kings Bay, Georgia was dredged with a water injection dredge head in September 1993. The magnetic silencing facility has an array of fiberglass tubes housing devices used to degauss submarines. Cables originating from a shore side facility control the devices. After dredging with conventional equipment to 41 ft below MLW, Wright Dredging Company used a fluidizing pipe to suspend the sediment around the tube array, and a conventional dredge was used to remove the remaining fluidized sediment. The fluidizing pipe discharged 125 psi water through 24 0.5-inch jets spaced 1 foot apart. Through this combination of equipment, the array was dredging to a flat level at 46 ft below MLW, with 3 to 4 feet of undamaged fiberglass tubing left above grade (Hampton, 1994).

3.3 Jet Arrays

Water jets can be configured into an array that pushes newly settled sediments away from the area covered by the nozzles. The shear stress required from the nozzles must be large enough to not only resuspend the newly settled sediment, but also to transport it into the path of a current that will take the sediment away from the site. The U.S. Navy has experimented with jet nozzle arrays in the Mare Island Naval Shipyard, in Vallejo, California. The experiments were conducted to see which configuration of nozzle arrangement, current alignment and nozzle characteristics produced the best scouring results (Dellaripa and Bailard, 1986). The results of the experiment indicated that scouring patterns vary according to the distance between the nozzle and the bottom, the size of the nozzle and the discharge velocity. The study area has a history of high

sedimentation rates - upwards of 12 ft/year. A total of three types of arrays were installed between 1977 and 1993.

All three arrays shared some common characteristics. The systems were synchronized to begin the cycle at the start of the ebb flow near the bottom (twice a day in a semidiurnal tide pattern). The system motivator in all three cases was a surface operated pump, which took in water from near the surface, and discharged to a single riser through a series of valves, and finally to the nozzles in a sequential order.

3.3.1 Spatial Jet Array

The first system installed was a spatial jet array, as shown in Figure 8. This system has a series of 70 2-cm nozzles that covered a 34 m by 20 m test area. The jets were distributed in sets of 7 along 10 branch pipes, which in turn were connected in pairs to the central manifold pipe. Pneumatic pinch valves located at the branch pipe just before the manifold pipe controlled the flow rate through the pipe. The control system consisted of an electronic logic circuit coupled with an electromechanical timing circuit. The control system monitored discharge/intake pressures and power consumption. In the event of a malfunction, the control system also shut down the array and activated an alarm.

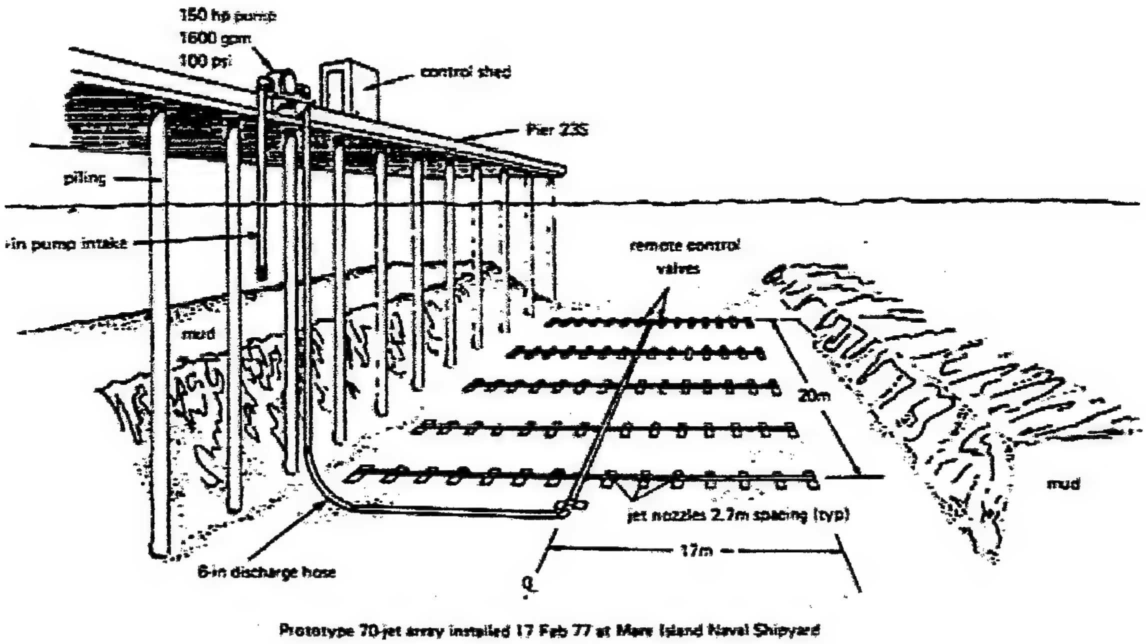


Figure 8. Mare Island Spatial Array.

The spatial array was operated twice a day for four months beginning in February 1977. The cycle consisted of a startup period, followed by seven minutes of flow to each pair of branch pipes in sequential order from the pier side units to channel side units. After the cycle, the system was placed in standby until the next ebb tide. The sequencing was designed to sweep the newly deposited sediment into the Mare Island Strait. A flow rate of 7.1 liter/sec passing through each jet had been estimated to provide a 100 percent overlap of scour patterns between adjacent jets. This estimate was based on an assumed sediment threshold stress of 1 dyne/cm^2, derived from experiments with diatomaceous earth. However, field tests showed that a shear stress of about 5 dynes/cm^2 was needed to prevent gradual deposition. The resulting scour pattern for each jet was significantly reduced, allowing small mounds of sediment to form between the individual jets. During the test period, the control area experienced approximately 0.5 m of sedimentation, while

the test area exhibited no measurable sedimentation, except for the aforementioned mounds.

3.3.2 Linear Jet Array

The linear jet array is an alternate configuration that is better suited to scour wharf areas. A linear scour jet array was installed and tested along a section of a 700-m long quay wall on the west side of Mare Island Strait. As shown in Figure 9, the linear jet array consisted of ten equally spaced jets distributed over 63 m of berth (Jenkins et al., 1981). The jets were connected to individual pneumatic pinch valves, which were in turn connected to a common manifold pipe. The manifold pipe was connected to the deck-mounted centrifugal pump through a single riser pipe. The 7.3 cm diameter jets were located 2.5 m above design depth (10.7 m MLLW) and pointing downward 20 degrees from horizontal. The jets were elevated above the bottom to avoid interfering with a rubble-rock toe located at the base of the quay wall. The downward angle of the jets provided a continuous scour pattern beginning at the outer edge of the rock toe. The linear scour jet array system uses the same centrifugal pump, pinch valves, and control system as the spatial array.

The linear scour jet array was operated for 18 months beginning in May 1979. During this time, the system duty cycle consisted of the following steps. At the commencement of ebb tidal flow, the pump was started and the discharge directed to the northernmost jet in the array. After 12 minutes, the flow was redirected to the next jet, and the process continued until all of the jets had been activated. The pump was then turned off, and the system placed on standby until the next tidal cycle. Preliminary bathymetric scans

showed that the test area shoaled approximately 0.6 m during the month prior to the start of the test. The bottom profile line shows that after two months of operation, sedimentation had been prevented out to a distance of 21 m from the face of the quay wall.

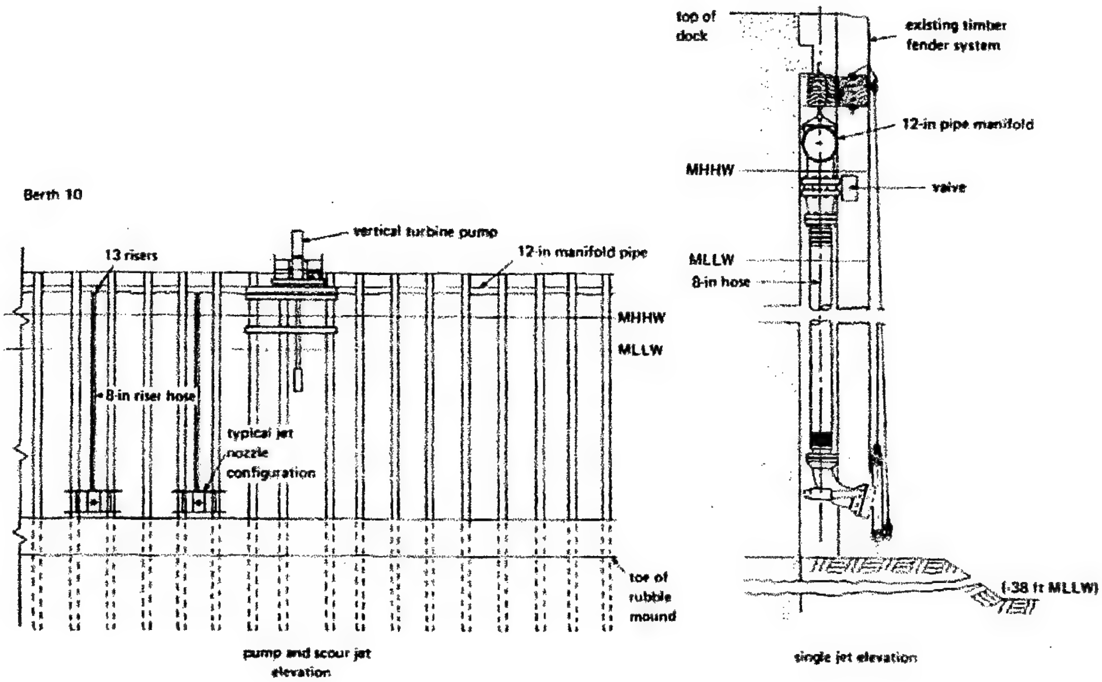


Figure 9. Mare Island Linear Jet Array

The above tests provided data relating to component reliability and system performance, and lead to significant findings. After about four months of operation, the rubber liners in the pneumatic pinch valves began to fail. This caused significant downtime for the linear jet array system, since divers were required to service the valves. Priming the deck-mounted centrifugal pump was a periodic problem due to loss of integrity of the pump seals. The PVC pipe used in both jet arrays was found to be brittle and subject to cracking. Finally, the electro-mechanical control system was found to be cumbersome

and unreliable. These findings led to a number of design improvements in subsequent scour jet array designs.

A prototype linear jet array was designed by the Naval Civil Engineering Laboratory to further develop the jet array concept. The prototype was installed at a quay wall berth at Mare Island Naval Shipyard. The prototype array consisted of 13 jets spanning a distance of 70m. The jet array was powered by a 285 liter/sec (4,500 gpm) vertical turbine pump having a discharge head of 27 m (90 ft). The jets were connected to the pump via individual riser hoses leading to a common manifold pipe. Flow to the jets was controlled by pneumatic-actuated butterfly valves, connected to the top of each riser hose. Both the valves and the manifold pipe were located above water allowing easy accessibility. Additional design features include quick coupling fiberglass pipe, a microprocessor based control system, and retractable jet support beams. The latter feature represents an important design improvement because it eliminated the need for divers during installation or maintenance.

The prototype array was used to systematically evaluate variations in jet geometry. A total of three jet diameters, three jet angles, three jet elevations, and three jet discharge rates were evaluated. The maximum design scour distance is 23 m using a design threshold stress of 6 dynes/cm^2. The prototype jet array provided the opportunity for comprehensive operational testing. The test bed scour jet array system was operated for three years beginning September 1986.

3.3.3 Turbo Scouring Units

The jet nozzle array systems use relatively small nozzles to clear an area next to a ship berth. Using larger nozzles with greater flow rates would provide greater scouring capability. Lessons learned during the development of the two jet array systems were applied to another system that prevents sediment from settling - the Turbo Scouring System from Scour Systems, Inc. - the patent holder (www.scoursystems.com). This system differs from the jet nozzle arrays in size and layout. Where jet nozzles were on the order of inches in diameter, the Turbo Scouring Unit (TSU) discharge ports are greater than 3 feet in diameter. Both systems use the principle of producing near-bottom water jets that induce entrainment. While the jet array nozzles typically scour the bottom out to 30 ft, the scouring distance for a TSU is greater than 150 feet for the 36 inch unit and 200 feet for the 42 inch unit. This system, like the two previous jet arrays, makes use of the currents associated with an ebb or flood tide to carry away the entrained sediment.

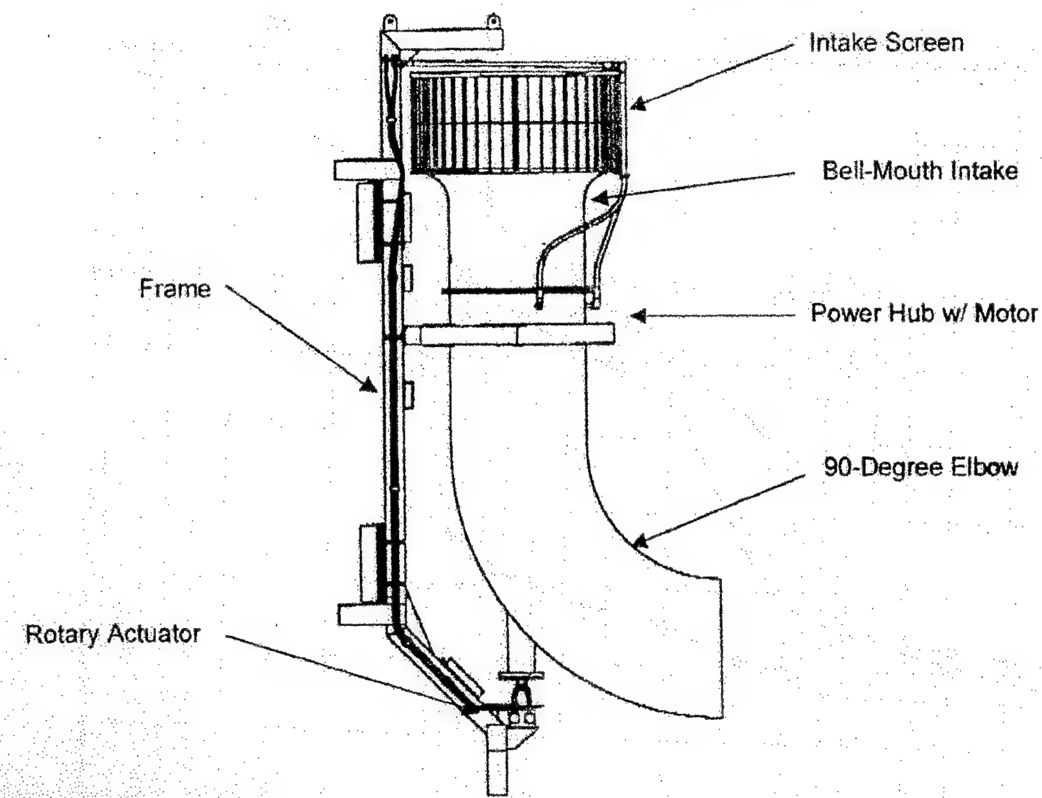


Figure 10. Turbo Scouring Unit

The Turbo Scour Unit has five main components: a steel intake grating to prevent debris from entering the unit, a fiber-reinforced plastic intake section, a steel drive hub, a fiber-reinforced elbow section and a steel support frame, as shown in Figure 10. Each unit is mounted on a guide pile and rail. The unit can be lowered and raised along the rail for periodic maintenance and repairs, as shown in Figure 11.

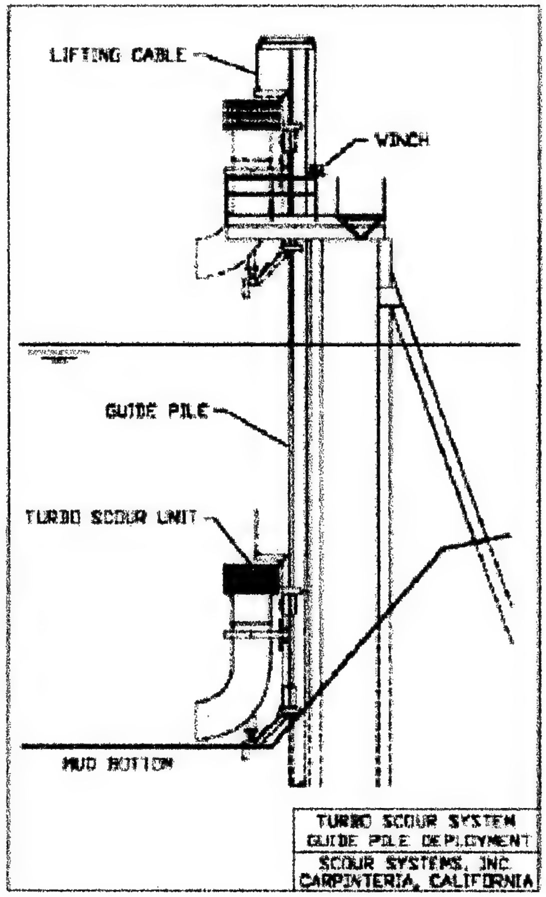


Figure 11. Maintenance Configuration for the TSU

Each unit has the capability to rotate 180 degrees horizontally, to increase the scouring area. Several units used together form a system that is controlled by a Windows-based computer. A single, central 75-hp hydraulic pump provides motivation to the hydraulic motor at each TSU. The cycle begins at a specified time, usually coordinated with an ebbing tide. The pump comes up to operating pressure and the flow is diverted to the first unit in the series while it is positioned at the point closest to the oncoming current. The TSU initial position depends on the design and environmental conditions, but is usually oriented perpendicular to the pier and the current, or parallel to the pier pointing

into the current. An individual TSU completes its cycle when it has rotated to a position parallel to the pier pointing with the current. The hydraulic pump flow is diverted to the next TSU in the series and the process continues until the last unit is finished.

Scour Systems has installed TSU arrays at Savannah, Georgia; Grays Harbor, Washington; and Wilmington, North Carolina. At the time of this writing, a larger system was being constructed at the Magnetic Silencing Facility at Kings Bay Submarine Base. The Wilmington system was installed along a terminal pier in a series of 8 units to keep the design depth at 40 feet below MLW. Monitored performance showed that after 8 months of operation, out to a distance 150 feet away from the dockline, the maintained depth was at 40 feet below MLW. This depth was maintained in an area that had a sedimentation rate of 12 feet annually. An adjacent terminal experienced 8 feet of shoaling in the same 8-month period. The Savannah site has 1 unit installed as a test, with plans to expand the total number of units to 5. The test unit has been successful at maintaining a 44-feet depth below MLW since installation in May 1998. An adjacent site experienced 10-feet of shoaling in a 4-month period. The Grays Harbor system consists of 3 units to cover half of one berth and has been in operation since 1996. The system has prevented shoaling within the zone of scour. The maintained depth is 32 feet below MLLW. The shoaling rate for adjacent areas varies between 8 and 12 feet annually. The system being installed at Kings Bay will have 9 units arranged to sweep sediment into a flood current, which was found to have a higher velocity than the ebb current. The common factor in all the cases discussed above is the presence of a significant river current. Once the TSUs have scoured the sediment from the bottom, the current moves

the entrained load downstream. In the case of Kings Bay the average current measured was 20 cm/sec.

3.3.4 Sand Bypassing

Sand bypassing plants have been in use for over 50 years in various forms as an alternative to conventional dredging, by transporting coarse grain sediment across an obstacle blocking the natural transport process. Manmade jetties and groins, and shipping channels are examples of obstacles capable of disrupting sediment flow parallel to the coastline. The operation behind bypassing is pumping fluidized sediment via a pipeline through the obstacle in question. The most common motivator is a jet pump, which is used to induce a venturi as shown in Figure 5. Low pressure at an orifice in an open section of pipe is generated by faster moving fluid flow inside the pipe. The faster fluid will pull external, sediment-laden fluid into the moving stream through the open section of pipe. The discharge pipe is placed in an area where the effluent can be released without impact on the environment and the recovered sediment can continue its movement along the shore. Jet pump applications in dredging are not at all limited to sand bypassing. Conventional dredging where suction is the main extraction method has long used jet pumps.

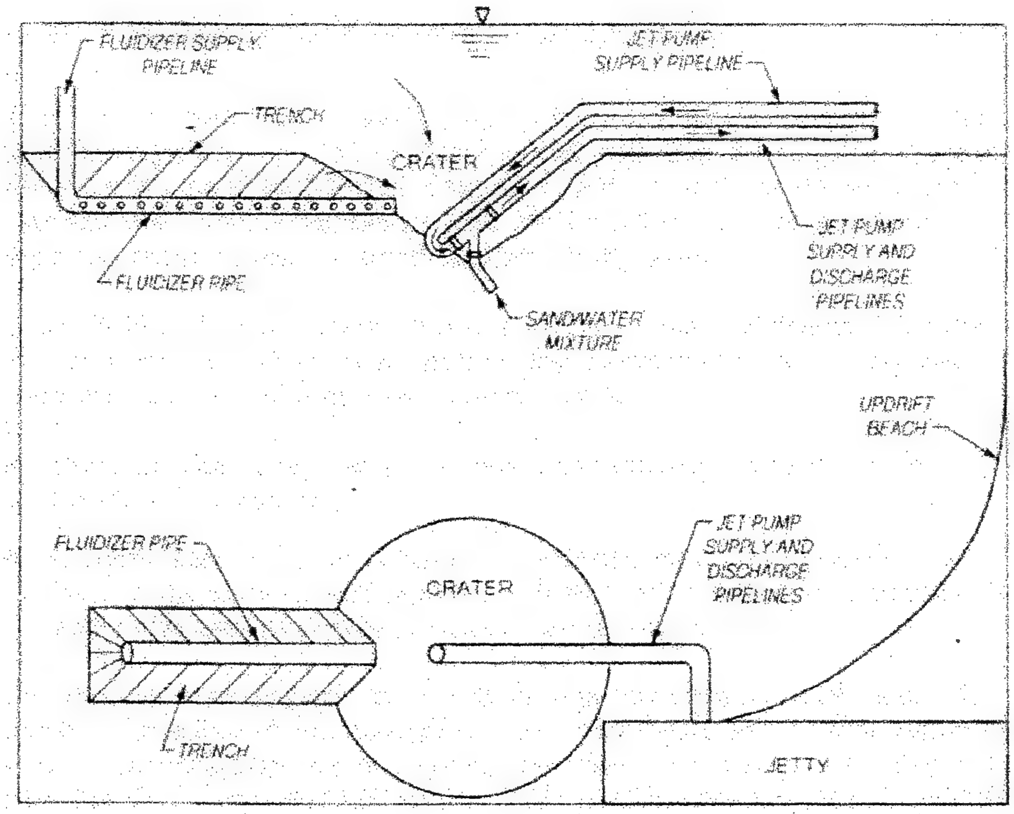


Figure 12. Sand Bypassing System

Figure 12 shows a typical sand bypassing system deployed inside a catchment basin that induces settling. There are three large, permanent sand bypassing plants currently in use: Nerang River Entrance, Australia; Oceanside, California; and Indian River Inlet, Delaware (Clausner, 1989, 1990). Using these production rates and problems encountered during operations at these three sites, the Army Corps of Engineers has conducted research as to what components work well in various conditions. Resistance to clogging by debris and production rates were two of the more important criteria examined during the testing. The benefits of using a jet pump include the ability to dredge to greater depths and continue dredging in buried conditions without the risk of cavitating, a reduced risk of blockage through long discharge pipelines, the ability to

work at any depth, and the reduced costs directly attributable to equipment wear when pumping abrasive materials. A booster pump may be required to compensate for reduced pressure head at the discharge point.

The sand bypassing technique is not directly transferable to fine grain material. The behavior between consolidated mud and sand is very different. Where the two have similarities is while the materials are in suspension or fluidized. Coarser material will settle out of suspension faster than fine particles so transport is an issue. Equipment has been developed that fluidizes a region so it can be fed to a central pumping area. Fluidizer pipes and jet pumps are usually used together in crater bypassing systems. Water Injection Dredging has demonstrated that fine grain sediment flows can be created in predictable ways (Sardinas and Krumholz, 1993). The density flow moves under the influence of natural currents or over an elevation or density gradient. If eductors are placed downstream of the density currents, the flows can be intercepted and bypassed.

4. PROPOSED STUDY SITE

4.1 General Site Information

The study site being used to determine the feasibility of sediment removal systems versus conventional dredging is Naval Station Mayport in Mayport, Florida. As shown in Figure 13, Mayport is situated at the mouth of the St. Johns River, which empties out into the Atlantic Ocean. The shipping channel in the St. Johns River is maintained at a depth of 42 ft to allow cargo shipping to proceed further up the river into the Jacksonville Port Authority harbor facilities. An inter-coastal waterway used for recreational boating intersects the river three miles upstream of the Naval Station. The river and inter-coastal waterway system drain several hundred square miles of low-lying land in northern and central Florida.

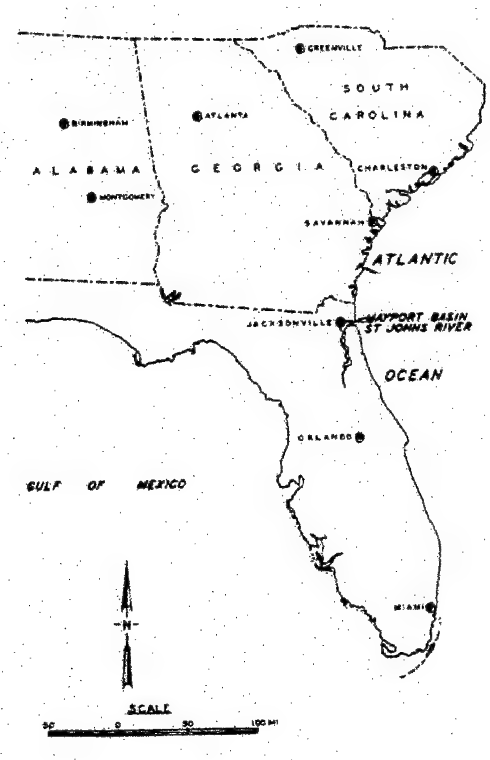


Figure 13. Study Site Location

The Navy harbor, or Ribault Bay is separated from the river by a small, narrow peninsula shown in Figure 14. The southern side of the harbor is an armored jetty that stabilizes the southern entrance of the river. The harbor water levels under the influence of the tides vary from 4.6 ft above MLW to 2.4 ft below. The maintained depth varies across the basin; determined by the type of ship being berthed at the adjacent pier. The design depth of the aircraft carrier piers is 50 feet below MLW. The design depth for piers supporting smaller ships (cruisers, destroyers, frigates, etc.) is 38 feet below MLW. The approach channel is maintained at 42 feet below MLW.

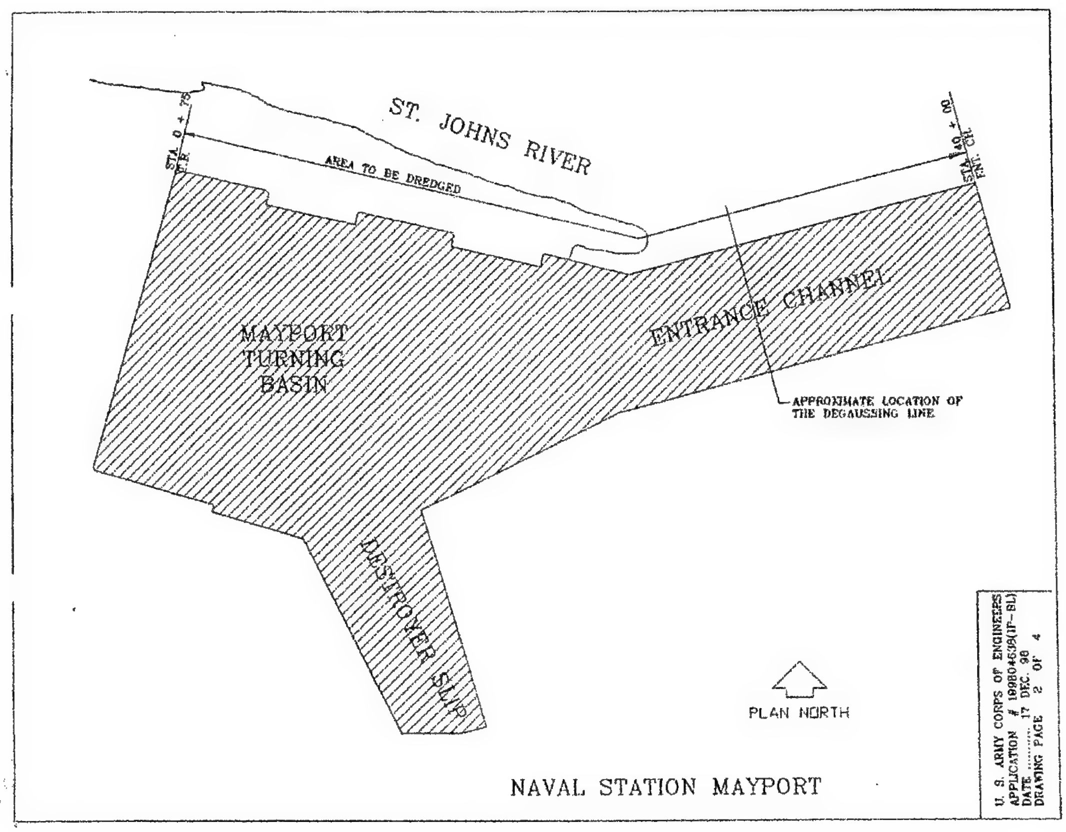


Figure 14. Mayport Basin

Water exits the harbor in two known mechanisms. The relatively narrow harbor entrance accelerates the ebb tide flowing out of the basin. The flow velocity of the river also drains the slower moving basin water. Both of these mechanisms are visible as surface currents. The water exchange mechanisms for subsurface layers are not known. The peak surface currents in the narrowest section of the entrance channel have been measured at 5 knots (Jenkins, 1983). The average velocity in the channel is reported as 1 ft/s and the average velocity inside the basin is 0.5 ft/s (Letter et al. 1987).

Water entering the harbor on the flood tide has the positive gradient working in its favor, the basin water level being lower than the river/seawater interface level. The river and seawater mixture at the river mouth is the major supply of water that refills the basin during the flood tides. The land surrounding the basin has been developed into pier facilities, effectively eliminating surface water runoff that is capable of carrying sediment into the basin (Letter et al. 1987). The harbor pilots have reported large eddies moving into the basin during flood tide. The presence of the vortex eddies raises the question how the sediment enters the basin. The vortices are speculated to mix the surface water and deeper layers, but without confirmation by water sampling through the water column this can neither be confirmed nor denied (Raichlen, 1986). Knowledge of the vertical sediment distribution of the water entering the basin through the entrance channel would help determine appropriate measures for handling the sediment – conventional, alternative, or a combination of both.

New piers have been constructed within the last few years. At berth FOXTROT, the previously open area has been built over with a pier designed to support a cruiser. Figure

15 shows the locations of all the piers at Naval Station Mayport. The effect that the Foxtrot pier had on circulation was not discovered until the D piers began to shoal at increased rates not previously seen before. This evidence that the current structure has been altered, essentially voids all previous studies about the basin characteristics. Should consideration be given to actually constructing any form of sediment control system in this harbor, a complete study must be conducted to establish the current patterns and velocities.

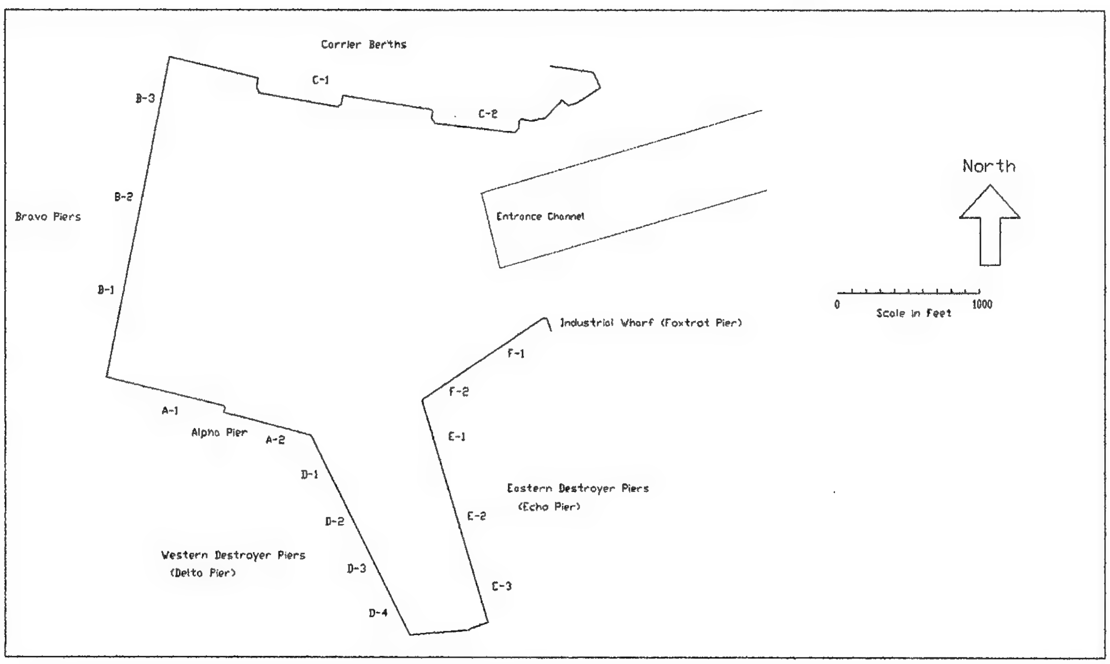


Figure 15. Naval Station Mayport Pier Locations

4.2 Site Characteristics

The sedimentation rate for the study site is currently reported as 5 ft/yr at the carrier berthing piers (Dept of the Navy, 1997). These are the deepest areas of the basin and should incur the greatest sediment load because of the quiescent waters. Dredging has been steadily increasing over the past several decades. The primary reason for this increase is the harbor expansion to handle more and larger vessels. The largest ship expected to use the facilities is a Nimitz-class aircraft carrier. A typical ship berthed at Mayport is an Arleigh-Burke class destroyer and a Ticonderoga class cruiser, both drawing 32 feet of water. The maximum number of vessels Mayport can provide berthing to is 34.

Despite the 50 plus years that Mayport has been in operation as a naval facility, the shoaling characteristics of the basin are not fully understood. The Army Corps of Engineers, between 1985 and 1987, conducted scale physical model and sedimentation analysis to define the basin dynamics (Letter, 1986). The Corps also took this opportunity to test various alternatives, to see if the sedimentation rate could be reduced. One of the proposed solutions was to construct a new breakwater beyond the C-2 carrier berth to prevent backwashing of river water during flood tides. Distorted scale modeling showed that extending a breakwater out into the channel by 1900 feet would prevent vortices from entering the basin, and the flood tide current would be altered. This option was considered to be too costly to implement. Another option looked at was excavating a venting channel. The channel would consist of a series of pipes leading from an upstream location, riverside of the carrier pier peninsula to the basin so the water level could equalize from the relatively sediment-free upstream water vice the sediment-rich

river mouth water (Jenkins, 1984). The concept would keep the basin water level constant to prevent the flood tide, sediment rich water from entering the basin. The series of pipes would be kept at an elevation high enough to permit the in-flow of river water only on the rising tide. Neither of these concepts was fully developed numerically nor by true scale model, so implementation could produce unpredictable results.

The results of the testing have established some published shoaling rates. However in recent years, shoaling in areas not previously reported as having problems has closed several berths. The position of ships influences the current patterns in the short time scale. The flow created around maneuvering vessels by propeller wash, added mass and the interaction with basin borders (sheet pile under the pier decks) induces scouring. The long-term current pattern changes brought about by the new pier facility in the Foxtrot area are a factor that must be considered. Yet another variable in the sedimentation rate would be the seasonal changes, including droughts, storms and hurricanes. The increased mixing in the littoral zone from storm energy (waves, wind and storm surges) and the influx of the mixed water into the river increases the sediment load. Droughts would reduce the flow of freshwater in the river causing seawater to move inland to compensate for the reduced water level. Taking all these factors into consideration, it is highly unlikely that the published shoaling rates provide an accurate picture of the current process.

4.3 Maintenance Dredging at Naval Station Mayport

The maintenance dredging quantities and costs for the period since 1954 are shown in Table 1. The Staff Civil Engineer Office at Naval Station Mayport provided this data.

The dredging frequency fluctuates around a two-year cycle, depending on the funding the Naval Station receives to dredge. As stated in the previous section, the dredge quantities have increased over the reporting period, due to the gradual development of the surrounding land into additional pier facilities, specifically the Echo and Foxtrot piers. More pierside area equates to more dredging. The current dredging quantity is 1.25 million cubic yards every two years. This value is not expected to increase since all available land has been developed into pier space. The costs have been adjusted to current year dollars by forwarding the cost per cubic yard annually, adjusting for inflation. From this data, the average cost to dredge the Mayport basin is $3.76/cu yd.

Table 1. Past Dredging History at Naval Station Mayport

Year	Quantity	Past Cost Cost	Past Cost/CY	Present Cost	Present Cost/CY
54	346312	$ 106,225.00	$ 0.31	$ 669,513.49	$ 1.93
56	897777	$ 241,502.00	$ 0.27	$ 1,472,496.74	$ 1.64
59	1411640	$ 258,554.00	$ 0.18	$ 1,479,937.43	$ 1.05
59	8992	$ 11,641.00	$ 1.29	$ 66,631.93	$ 7.41
61	1363070	$ 297,824.00	$ 0.22	$ 1,670,648.62	$ 1.23
61	10280	$ 9,658.00	$ 0.94	$ 54,176.71	$ 5.27
62	559092	$ 140,180.00	$ 0.25	$ 776,020.93	$ 1.39
64	289050	$ 152,040.00	$ 0.53	$ 820,140.44	$ 2.84
65	1962067	$ 545,954.00	$ 0.28	$ 2,889,528.65	$ 1.47
66	868479	$ 482,473.00	$ 0.56	$ 2,468,149.68	$ 2.84
69	716858	$ 240,187.00	$ 0.34	$ 1,072,230.05	$ 1.50
69	441323	$ 513,505.00	$ 1.16	$ 2,292,361.76	$ 5.19
72	570972	$ 735,651.00	$ 1.29	$ 2,912,950.28	$ 5.10
74	547565	$ 475,810.00	$ 0.87	$ 1,542,733.43	$ 2.82
75	736084	$ 943,285.00	$ 1.28	$ 2,859,960.76	$ 3.89
78	1789701	$ 2,523,904.00	$ 1.41	$ 6,273,494.59	$ 3.51
78	173558	$ 214,863.00	$ 1.24	$ 534,070.18	$ 3.08
79	47148	$ 161,875.00	$ 3.43	$ 355,160.70	$ 7.53
82	1793031	$ 4,410,000.00	$ 2.46	$ 7,603,674.17	$ 4.24
83	81363	$ 284,341.00	$ 3.49	$ 472,355.40	$ 5.81
83	48000	$ 283,500.00	$ 5.91	$ 470,958.31	$ 9.81
84	1200000	$ 3,059,500.00	$ 2.55	$ 4,889,397.67	$ 4.07
87	1200000	$ 3,010,500.00	$ 2.55	$ 4,461,506.95	$ 3.72
89	733000	$ 3,371,000.00	$ 4.60	$ 4,498,491.95	$ 6.14
91	1200000	$ 2,968,000.00	$ 2.47	$ 3,621,809.79	$ 3.02
93	1100000	$ 2,510,000.00	$ 2.28	$ 2,896,931.72	$ 2.63
97	1024000	$ 2,100,000.00	$ 2.05	$ 2,190,996.11	$ 2.14
99	1255234	$ 4,900,000.00	$ 3.90	$ 4,900,000.00	$ 3.90

5. DESIGN

5.1 Options

Several alternate siltation removal systems are possible for Naval Station Mayport. Which system would produce optimal results depends highly on the environmental conditions at the site, how much funding is available for the procurement and operation of the system, and how detailed the modeling studies are.

Option 1 is installing a series of turbo scouring units along the piersides. Figure 16 illustrates this concept. Assuming that the ebb current is sufficient to transport resuspended sediment out into the river current, the turbo scouring units alone would be able to keep the basin free from sedimentation. Dispersion from the TSU scouring action should provide some current, and the ebb current also moves water out of the basin. Prior studies have reported an average current inside the basin of 0.5 ft/s (Letter et al. 1987). However, a conservative assumption is the that this option would not provide adequate sediment removal out of the basin. Without the benefit of sweeping currents, like those provided in a river, the sediment particles will eventually resettle at a location beyond the influence of the turbo scouring units. Testing the sediment behavior would provide insight into how long the particles will stay in suspension and what distance the sediment flow would cover before settling out. A thorough basin analysis determining current flow patterns in the different layers of the basin and the velocities at critical areas would provide this information.

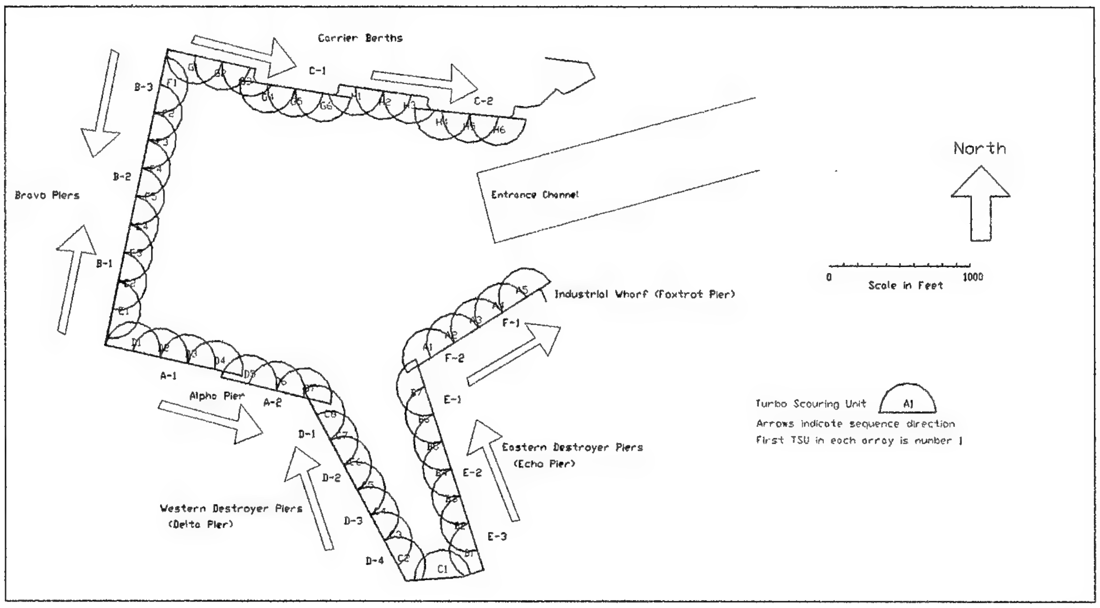


Figure 16. Turbo-Scour Unit Arrangement – Option 1

Option 2 includes the TSU series in option 1 and adds several jet pumps to transport the entrained sediment out of the basin, as shown in Figure 17. The jet pumps could be used to move the sediment from the central basin area in a manner similar to how sand bypassing systems move sand. The main difference here being the jet pumps would be moving a mixture of seawater, river water and low concentration fine sediment instead of high concentrations of sand. The jet pumps would remove the still suspended sediment out into the river currents during ebb tide via an underwater pipeline. An area 1610 feet by 1610 feet in the central basin should be overdredged to 60 feet below MLW to form a catchment area. The catchment area will promote settling in the vicinity of the jet pump arrays.

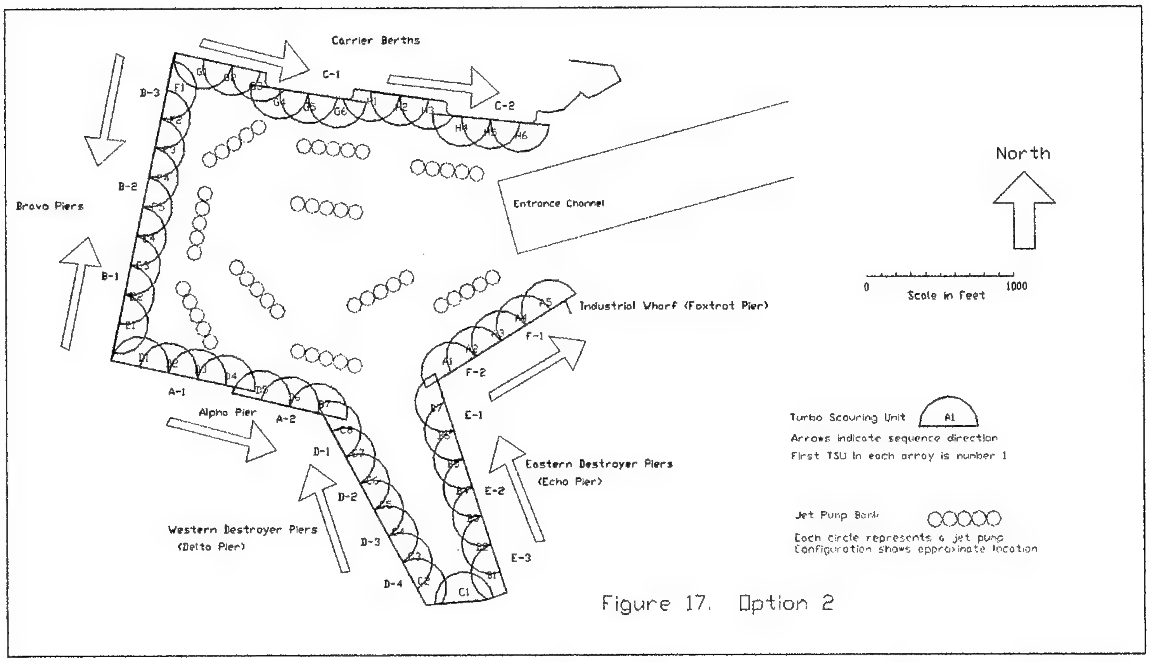


Figure 17. Jet Pump System, TSUs and Catchment Basin – Option 2

Figure 18 shows the configuration for option 3. This option would use the TSU arrays in option 1 to sweep the sediment into the turning basin. The overdredged catchment basin described in option 2 is included to promote settling of sediment entering the basin. Periodic maintenance dredging is required to remove the sediment. The sediment load in this option is not the 1.25 million cubic yard loading currently reported. A reduction in the actual amount of sediment that settles is expected due to the presence of the TSU arrays. The scouring action of the TSUs will provide some mixing that will keep the sediment particles in suspension. Combined with the expected mixing from the flood tide, a portion of the entrained sediment should be removed by the ebb tide. A ratio of the basin water volume at MLW water level and the additional water volume that enters and leaves the basin due to the tides provides a reduction factor in the sediment load. The average reduction factor over a 3-year period is 9%. Application of this reduction factor

results in a maintenance dredging cycle of 3-years with a new total of 1.71 million cubic yards. The catchment basin is a much smaller area that is easier to access and therefore should be faster and easier to dredge than the existing basin.

The final option is to continue the current maintenance dredging operations.

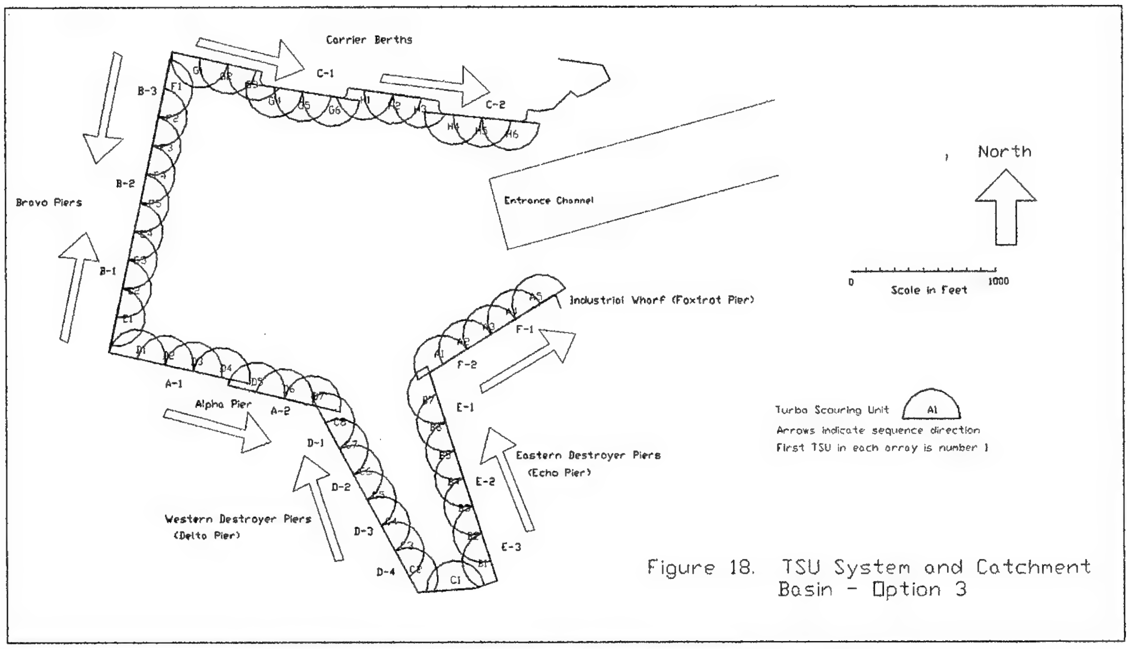


Figure 18. Catchment Basin and TSUs – Option 3

5.2 Destroyer Slip Issues

Historically the destroyer piers have not had problems with shoaling. However in light of the recent emergency dredging operations and the construction of the new pier at the Foxtrot location, it would be prudent to assume that the circulation structure has been altered and sedimentation will occur in the future. Prior to construction, the Foxtrot pier area was very shallow when compared to the adjacent destroyer slips, which effectively prevented current from the entrance channel from moving into the destroyer slips. The area was dredged to prepare for the new pier, which has a design depth of 37 feet MLW.

With the development of this area, circulation and sedimentation now occurs within the destroyer slips. The use of TSU's is recommended along the pier-side to keep the ship berthing areas free from sedimentation, regardless of current or future deposition patterns. As with the carrier piers, the issue remaining is how to handle the cleared sediment where there are no constant currents present that are strong enough to carry the sediment away. The problem is further complicated in this area because of the slope gradient; the westerly destroyer slip is designed to have a 30 foot depth, and the easterly destroyer slip is designed to have a 35 foot depth. The location and operational sequencing of both the TSU series servicing the destroyer slips are shown in Figure 19. The sequencing of the TSU's can alleviate a portion of the problem. Installing two independent systems at the destroyer slips, one each at the eastern and western halves, and operating the eastern series of TSUs out of phase (lagging) behind the western series can prevent redepositing of the sediment cleared from the 30 foot section in the 35 foot section. The lag can be accomplished by allowing the western series to start its cycle about one hour ahead of the eastern series. With the lag, the eastern series will be able to intercept any sediment still in suspension, scoured by the western series. The eastern series has to work against the higher elevation that the western destroyer slips are maintained at, so the scoured sediment is not anticipated to settle back onto the western slips. This needs to be verified by testing.

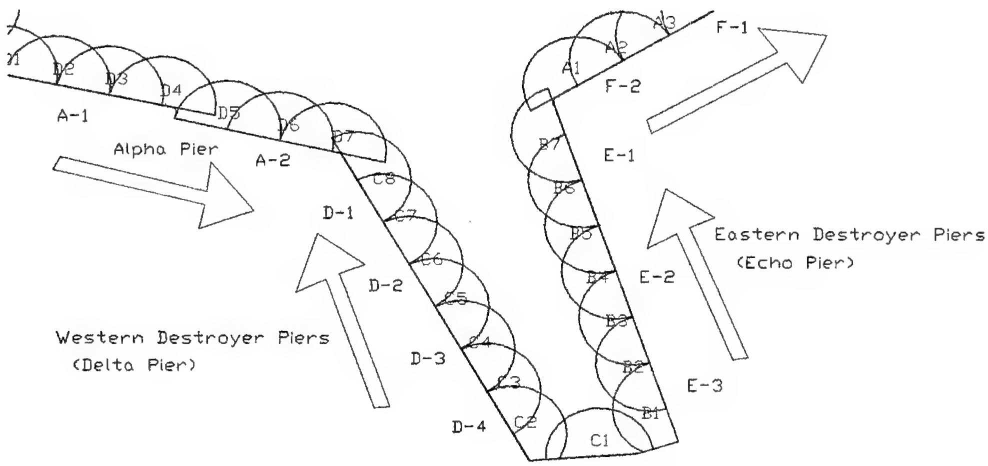


Figure 19. TSU Arrangement at the Eastern and Western Destroyer Piers

Each of the two TSU series in the destroyer basin would provide coverage for approximately 1/3 of the total destroyer slip area. The remaining central 1/3 of the area would experience a gradual build up of sediment. This build-up could be cleared by dredging or by a fluidized mud removal system. Sequencing can also be used to create a net flow near the bottom, from the inner most berths to the berths closest to the turning basin – to effectively eliminate future maintenance dredging in the destroyer slips. This is highly dependent on the fluid momentum generated by the TSUs and synchronization with the ebb tide.

The issue of synchronizing the TSU series with the ebb tide is questionable. If after conducting basin studies it is determined that there is a current strong enough to carry the scoured sediment out into the St. Johns River, timing (which units are active and the duration each unit is run) is a crucial factor. If no suitable currents are found, sequencing

the TSUs to maximize sweeping effects and prevent resettling in areas already scoured should be the driving factor.

The operation of the TSUs in this area will also induce vertical circulation, as near-surface water is sucked downward to supply the TSU intakes. The overall effect will be a scoured region through the TSU effective radius, and mixed suspended sediment in the area between the two TSU arrays. The expected net current flowing out of the destroyer pier area due to the sequencing of the TSUs may not fully develop because of the 180° rotation and sequential operation. As one TSU completes its cycle, the next will begin with the discharge aimed at the area just completed by the last TSU, effectively scouring against the current established by the previous TSU. However, with the sequenced operation, dispersion through the sequenced TSU activation will still occur. Calculated from Stoke's Law, the fall velocity for a 0.015 mm particle in totally quiescent seawater is 0.00002282 m/s. Based on the conditions present in the destroyer basin, the sediment should still migrate into the catchment basin.

5.3 Carrier Pier Issues

Because of operational sensitivity, the carrier berth C-1 was dredged to a depth of 50 feet. The requirement for a conventionally powered aircraft carrier is 42 feet, but the frequency of cooling system problems due to intake of sediment prompted a test to see the effect of providing a deeper berthing. The result has been positive – there have been no reports of sediment uptake into the cooling systems since the 50-foot basin was excavated (McVann, 2000). The area still experiences shoaling, but the biannual dredging cycle frequency is sufficient to prevent levels viewed as critical from occurring.

Extending this principle to the entire basin, excavating a deep collection pit in the center of the basin could prolong the time between dredging cycles. The scoured sediment will move away from the pier-side under the influence of the momentum in the TSU discharge water, and begin to settle out when the momentum is dissipated. The area can be dredged when levels have reached a certain depth, and the operation would have a shorter duration because of the well-defined, smaller area. Without conducting simulations, the rate can only be hypothesized, but with the same sediment load entering the basin and the TSUs/hole focusing the deposition, it is reasonable to assume the actual frequency of required dredging in the collection area will be a function of hole depth. A shallower collection area would require dredging at least every two years, a deeper hole could extend the time between dredging cycles.

5.4 Central Basin Issues

An alternative method to conventional dredging would be to fluidize the mud (sediment accumulation) and pump it via a pipeline or trench to the St. Johns River where the strong currents will sweep it away. Extensive studies have been conducted on sand bypassing systems, but applications have been slow to transfer over to flocculated sediment. Comparisons between sand and fine-grained mud/organic sediment can be made as far as pumping is concerned (WID initiated, sand bypassed transport – as water is drawn out of the crater/trench new water fills in), as long as both types of sediment are in suspension. The deep collection pit discussed in the previous section should be excavated in the central part of the basin and destroyer slip. The sediment scoured away from the pier-sides will begin to settle in the deep collection pit. The time to resettle can vary between a few hours for relatively coarse particles to several days for finer particles. A series of

Bernoulli (jet) pumps can be placed inside the collection pit to remove the still fluidized mud. Equipment for this system is readily available – fire hoses for freshwater supply, off-the-shelf submersible pumps and polyethylene pipe with heat-sealed joints. For maintenance purposes, the only portion of the system actually fixed to the bottom should be the pipeline running out to sea. The pumps should be seated on concrete blocks, but otherwise free to be relocated by divers for periodic maintenance or placement to more critical areas where sediment flow rates are higher. Freshwater or surface seawater supply to the jet pumps should be from pier-side water hydrants or pumps through fire hose type lines. If the sediment is not staying in suspension long enough, or is not moving far enough to the deep collection pit, fluidizer pipes can be used to augment the momentum generated by the TSUs and/or initiate a density flow.

5.5 Bottom Material Assumptions

Because of time constraints and lack of financial assistance and equipment for procuring sediment samples, this report is limited to the use of past records from the study site to provide a design for use as a basis for establishing costs. At the Mayport site, dredging records indicate that several dredging cycle spoils have been disposed of in an upland disposal site located at the Mayport Naval Air Station. To ascertain a predominant particle size for use in determining system parameters, a sediment sample report was referenced to determine the sediment characteristics from previous dredging cycles (PPB Environmental Laboratories, 1993). The report acknowledges that the particles have had considerable time to consolidate and change properties from what would be found in-situ in the basin. There are two separate and distinct dredge spoils disposal areas. Three samples were taken from each site and analyzed for plasticity characteristics and particle

size distribution. The area listed as Disposal Site 1 was primarily used to dispose of capital dredging spoils from harbor expansion projects. This site contains mostly sand sized particles. Disposal Site 2 was used to dispose of maintenance dredging spoils and contains mostly fine sized particles. The mean particle size in disposal site 1 was 0.15mm, and the mean particle size in disposal site 2 was 0.10mm. Although these sizes are indicative of sand, visual classification notes taken during the boring operations indicate that the material is composed of silt. This observation should be considered due to the changes expected when this type of material is allowed to consolidate (National Academy Press, 1987).

An extensive study was performed at the Kings Bay project site to provide design criteria for the Magnetic Silencing Facility (Hampton, 1994). When compared to the mean particle size found in the Kings Bay study (0.015mm), the Mayport values are quite large. As stated above, the primary reason for the difference is attributed to the two very different conditions in which the sediment samples were taken – the Kings Bay samples were new, unsettled fluidized mud, while the Mayport samples were a composite sample from several dredging cycles, which had been allowed to consolidate.

The particles being fed into both the St. Johns River and the St. Marys River have very similar geological backgrounds and enter the estuary region in a similar fashion. The mouths of the two river systems are only within 40 miles of each other. It is reasonable to assume that the sediment particle sizes found in the two areas are similar as well. The discrepancy is most likely attributed to morphological changes of the fine material from the consolidated mud composed of flocculated material into stratified layers of mud that

is further consolidating with the decrease in water content. The void spaces present in the flocculated material would collapse under the pressure of additional loading (split-spoon samples were taken down to 20 feet) and dewatering of the berm. An assumption being made is that the actual particles present in the berthing areas are much smaller than the particles found in the disposal site. Based on the similarity between the two river systems, the particle size will be assumed to be 0.015mm. The TSUs installed at Kings Bay were sized to provide enough force to scour the Magnetic Silencing Facility pier. The proposed TSUs for Mayport will provide an even greater discharge flow, due to its larger size. If the particle size assumption is correct, there should be more than enough energy to scour the pier-side areas.

There is very little data available describing the current patterns and velocities for Mayport. Sediment influx studies used aerial photographs to arrive at the conclusion that the influx of water moving into the basin is limited to the surface down to a depth of a few meters (Bailard, 1984). Observations of surface activity during tide changes show large velocity gradients only near the harbor entrance. Eddies are formed off the tip of the carrier pier peninsula during flood tides and enter the harbor. The harbor pilots have also indicated that the vortices are long lived. This leads to the assumption that there is very little current inside the basin area. Otherwise the vortices would be sheared and disorganize. The assumption that there is very little to no current activity in the basin would support the results of bottom samples taken in 1980 (Bailard, 2000) that there was a high percentage of mud and very little sand. Coarse grain material would require a stronger current to move into an isolated basin such as this.

5.6 Proposed Configuration

The conditions found at Mayport do not favor a specific system; the two decisive factors being the lack of a strong, cyclic current within the basin (prevents sweeping) and the fine size of the sediments (harder to pump). The four concepts presented in section 5.1 are reduced to three options. Option 1 is a combination of two systems placed to handle the given environmental conditions. Along the berthing areas, 42-inch turbo scouring units should be used to prevent sediment from settling in these critical areas. Within the central basin, capital dredging to excavate a deep collection pit and placing jet pumps along the bottom would transport the sediment back into the river at approximately the same rate it left to enter the basin. Option 2 is a scaled back version of option 1, excluding the installation of the jet pump array. Option 2 relies on maintenance dredging to remove settled sediment from the catchment basin. The maintenance dredging occurs on a 3-year cycle, and would remove 1.33 million cubic yards. Option 3 is continued maintenance dredging at the current frequency and quantities.

5.6.1 Option 1

Based on product specifications, the turbo scouring unit layout for protecting the piers is provided in Figure 16, each half circle represents a single TSU, and the area it scours. There are 48 turbo scouring units in the series, which would provide scouring out to 200 feet from the pier. The system would have to be divided into sections, which would be operated independently from one another, so that jet sequencing and synchronizing with ebb tide (in whatever degree is available) can be accomplished within the tidal cycle window. The breakdown would divide the system into 8 sections, which would run simultaneously using separate hydraulic motors and controlling systems.

The scoured sediment would move out of the immediate pier side areas under the influence of the TSU momentum. In option 1, the suction from the bottom mounted jet pumps, and the ebb current if available, would continue to move the sediment as the initial TSU momentum runs out. In areas closer to the entrance channel, the effect of the ebb tide should be greater than in areas closer to the back of the basin. The jet pumps would be used to collect sediment from the back part of the basin into a submerged pipeline for discharge outside the main shipping channel or on the downstream portion of the southern breakwater. The jet pumps have a zone of influence where fluid within a certain radius will be drawn towards the intake orifice. Arranged in two rows that provide overlapping coverage, the scoured sediment entrained in the discharge plumes of the TSUs would be drawn into the jet pumps. The jet pumps should be mounted atop concrete pads for navigational purposes (easy to pinpoint their location) and to avoid unnecessary dredging of bottom material. The jet pumps should begin running shortly after the start of the TSU cycles so that the entrained sediment is intercepted. The time required for the sediment to resettle is on the order of hours to days. If the jet pumps are allowed to run during the period of time from just after the start of the TSU cycle until a couple of hours after the cycle completion, or until the flood tide begins, the newly scoured sediment should be effectively removed from the basin.

Although the jet pumps specified are capable of moving greater concentrations of denser material, they are also capable of moving large volumes of water, which is what a majority of the fluid will be. By dividing the total, modern bi-annual sediment load of 1,255,234 cy of sediment by the total number of cycles the alternative system will go through during the same two-year time period, the sediment influx/removal rate is 860

cy/cycle. The actual volume of sediment-water mixture produced by the TSU system would be much greater, approaching 28.5 million gallons per cycle, based solely on the output of the TSUs. With a quantity of this magnitude being moved every 6 hours, adequate suction coverage from the jet pumps becomes the important factor. Slightly over sizing the jet pumps would increase the likelihood that the entrained sediment load is removed from the basin. Also modifying the intake sections to draw water in a lower vertical, wider horizontal profile would help isolate the suction to the layer containing entrained sediment. The pump manufacturer could make this modification. Also, using water drawn from the river at an upstream location, especially in the carrier basin could provide additional head to drive a current flowing out of the basin. This last option is similar to the proposal to use a canal to take water during flood tide and use it to compensate for the inequity in the basin (lower water elevation inducing sediment laden flow into the basin) and would require numerical and physical modeling prior to implementation.

The TSU jet plume determines the arrangement of the jet pumps that will be used to transport the suspended sediment out of the basin. Intercepting the sediment-water mixture before the sediment begins to settle is required to ensure that jet pump suction alone can move the sediment out of the area. This assumption is critical. If the sediment does settle before being entering the suction cone of the jet pumps, there will be no easy way to remove the sediment. A secondary consideration is the sediment that does not make it to the piers, but settles in the turning basin areas. If spaced throughout the deep catchment basin, the jet pumps can also intercept sediment deposits around the pumps. The proposed layout is presented in Figure 17 and shows the primary line of pumps on

the perimeter of the deep catchment area, and the secondary pumps on the interior of the deep catchment area. For the purposes of developing a planning estimate, the pumps specified are far more capable than what is actually required. The jet pump is capable of moving solids in slurry form at 500 cu yd/hour. The task required is moving water with a very low concentration of sediment at 500 cu yd/hr. This should ensure adequate pumping capacity.

The jet pump discharge lines would converge at a manifold where they would flow into a single discharge main. A centrifugal booster pump would be used to produce enough head to motivate flow out to sea. There are two options for the discharge pipeline. The first would be to run the submerged pipeline along the entrance channel, into the main shipping channel and discharge the sediment at a point where it will not migrate back into the basin and where it will not affect the shipping channel. The second, preferred option would be to bury the pipeline along the landside of the southern jetty, until it reaches the Atlantic Ocean, and then run the pipeline submerged out to the offshore dredging spoils disposal site or a closer site depending on costs and environmental concerns.

The pipe should be constructed of heat welded, high-density polyethylene. Heat welded seams would provide the best safeguard against leakage and would allow for some flexibility. The smooth surface of high-density polyethylene would slow the growth of marine organisms, and would reduce the head required to move the flow through the pipe due to low friction factors. An engineering estimate of the pipe size is 20" diameter, which is based on the 6-hour time window for transporting the scoured sediment and a conservative flow velocity of 1 meter/second (see Appendix B). Within the basin and in

areas where the pipe is exposed (underwater), the pipe should be anchored to concrete blocks to prevent shifting, to keep the pipe from floating, to prevent damage during storm conditions and to avoid becoming a navigational hazard. Laying the buried, underwater section of pipe running out to sea, could be accomplished by using micro-tunneling equipment or modified water injection assisted cable plows (Leifer et al. 1999).

The preferred configuration would be to install the pipe on the landward side of the southern jetty. This location would take advantage of the protection offered by the jetty and it would be less expensive than laying the entire pipeline in a shipping channel (hampering shipping, providing sufficient protection, installation costs). Using a small ship capable of operating a submerged cable plow and laying the pipe simultaneously is the recommended installation method. The costs to install the pipe in this area should be significantly less since the in-water work is reduced. The in-water installation that remains is in sand and in an area free of large obstacles. The location where the pipe is laid and how much exposure it has to wave action will determine if armor protection is required. A hurricane analysis should be performed to ensure the buried pipe would withstand the event. The cost of armor will raise the capital and maintenance costs for this option.

The system should be installed immediately after a conventional maintenance dredging cycle to provide a bottom profile that can be maintained by the equipment – unconsolidated mud (low strength) versus stiffer, consolidated mud (higher strength) - and to use the equipment to excavate the central basin to the deeper depth (capital dredging).

5.6.2 Option 2

This option is similar to option 1, except for the exclusion of the jet pump system. The operational costs of the jet pumps are comparable to the bi-annual maintenance dredging costs. This is due to the high, energy requirements of the pumps. Omitting the pumps re-introduces maintenance dredging as the primary means of sediment removal. With the catchment basin in place, the maintenance dredging will be confined to a smaller area in the center of the turning basin, which is away from the piersides. Using the right equipment, the catchment basin could be dredged in less time and with less impact to harbor operations than the current maintenance dredging operations. For the purposes of this study, a catchment basin depth of 60 feet below MLW is specified. This depth will allow 1.7 million cubic yards to collect in 3 years. The additional cost of this option above the cost of conventional dredging on a 2-year cycle is the expense of providing 100% berthing availability.

5.6.3 Option 3

Continued maintenance dredging is a realistic option that must be considered until such time when technology and economics effectively reduce the cost of alternate sediment removal systems. The existing bi-annual frequency and 1.25 million cubic yard quantity will be used in this study. Provided adequate disposal sites remain available and the quality of the spoils meets current disposal standards, conventional dredging offers an economically feasible method of maintaining design depths.

6. ECONOMIC ANALYSIS

6.1 Projected Dredging Cost – Option 3

The current method of maintaining the required depth is by hopper or hydraulic dredging at a frequency of every two years. The cost per cubic yard over the past 45 years was determined to be $3.76. The cost to continue maintenance dredging at the past frequency, for the next 30 years at current quantities, is $57,348,483.52 as shown in Table 2. The future dredging costs were calculated by applying a 4% inflation rate to the biannual cost. The inflation rate was chosen based on the stability of inflation in the past decade. The present value of the future dredging costs was obtained by adjusting the future values by 6% present cost of money. The cost of money rate was selected on the recent trends in U.S. Government Bonds interest rates. A two-year dredging cycle was used to calculate the projected costs based on the average past frequency over the past 45 years. The quantity was fixed at the current amount of 1,255,000 million cubic yards during each cycle.

Table 2. Present Value of Future Dredging Costs

Option 3 - Bi-Annual Dredging		
Quantity (cu yd)	Cost/cy	Cost
1255000	$ 3.76	$ 4,718,800.00
	Future Costs Adjusted for 4% Inflation	Present Value Considering 6% Cost of Money
Present 1-year	$ 4,718,800.00	$ 4,451,698.11
Cycle 1 (year 2)	$ 5,103,854.08	$ 4,542,411.96
Cycle 2 (year 4)	$ 5,520,328.57	$ 4,372,617.28
Cycle 3 (year 6)	$ 5,970,787.38	$ 4,209,169.50
Cycle 4 (year 8)	$ 6,458,003.64	$ 4,051,831.37
Cycle 5 (year 10)	$ 6,984,976.73	$ 3,900,374.52
Cycle 6 (year 12)	$ 7,554,950.83	$ 3,754,579.11
Cycle 7 (year 14)	$ 8,171,434.82	$ 3,614,233.50
Cycle 8 (year 16)	$ 8,838,223.90	$ 3,479,133.99
Cycle 9 (year 18)	$ 9,559,422.97	$ 3,349,084.49
Cycle 10 (year 20)	$ 10,339,471.89	$ 3,223,896.21
Cycle 11 (year 22)	$ 11,183,172.79	$ 3,103,387.45
Cycle 12 (year 24)	$ 12,095,719.69	$ 2,987,383.29
Cycle 13 (year 26)	$ 13,082,730.42	$ 2,875,715.35
Cycle 14 (year 28)	$ 14,150,281.22	$ 2,768,221.54
Cycle 15 (year 30)	$ 15,304,944.17	$ 2,664,745.83
Total 30 year cost		**$ 57,348,483.52**

6.2 Projected Costs of Option 1

The cost to install, operate and maintain the system as proposed for the next 30 years is $74,381,923.70 as shown in Table 3, which comes to a total of 30% more than the cost to continue dredging. The annual expenses are based on manufacturer suggested schedules and have been adjusted for an assumed, constant, annual inflation rate of 4% and converted to present value using a cost of money rate of 6%. If analysis indicates the need for armor protection, the cost for this option will increase.

Table 3. Capital and Projected Operation and Maintenance Costs for Proposed System

	Annual Cost	Total Present Value
Operation	$ 2,160,505.61	$ 48,821,872.49
Maintenance	$ 258,200.00	$ 5,844,399.61
Capital Expense		$ 19,715,651.60
Total for Option 1		**$ 74,381,923.70**

6.3 Projected Costs of Option 2

The cost to install, operate and maintain the system as proposed for the next 30 years is $82,427,533 as shown in Table 4, which comes to a total of 44% more than the cost to continue dredging. The annual expenses are based on manufacturer suggested schedules and have been adjusted for an assumed, constant, annual inflation rate of 4% and converted to present value using a cost of money rate of 6%.

Table 4. Capital and Projected Operation and Maintenance Costs for Proposed System

	Quantity (cy)	Unit Cost	Cyclic Cost	Total Present Value
Operation			$ 411,157.94	$ 9,306,627.91
Maintenance			$ 86,400.00	$ 1,955,678.26
Capital Expense				$ 17,393,151.60
Maintenance Dredging	1713691	$ 3.76	$ 6,443,476.28	$ 53,772,075.50
Total for Option 2				**$ 82,427,533.27**

6.4 Total Cost Discussion

The cost discussion is based solely on capital, operation and maintenance costs and the results of this study are presented in Table 5. When considering total costs, the effect that

each option has on the environment and the benefit of operational readiness should be introduced into the final analysis.

The ability to dock a ship on time has a significant cost associated with it. The cost of operational readiness in terms of conventional dredging is the expense of unscheduled maintenance dredging. This type of operation is excessively expensive due to high mobilization costs and loss of economies of scale. Operational readiness is inherently provided in the options using scouring equipment. The scouring system will keep the berths sediment free. These systems involve larger initial capital costs, but the constant availability of the berth over the life cycle of the alternate sediment removal system is a benefit.

The cost of protecting the environment is difficult to quantify because of the wide-reaching effects. The health of indigenous wildlife, the tourism in the area, fisheries and other industries may be affected in some way. Without quantifying the environmental benefits/impacts of each option, the total cost cannot be presented. However, from the discussions of this paper, the benefits offered by the alternate sediment removal systems and the cost of providing high-confidence operational readiness could bring the costs of options 1 and 2 back down to a comparable level with conventional dredging.

Table 5. Summary of Option Costs

Option	Capital	Maintenance Costs	Operation Costs	Maintenance Dredging	**Total Cost**
1	$ 19,715,651.60	$ 5,844,399.61	$ 48,821,872.49	-	**$ 74,381,923.70**
2	$ 17,393,151.60	$ 1,955,678.26	$ 9,306,627.91	$ 53,772,075.50	**$ 82,427,533.27**
3	-	-	-	$ 57,348,483.52	**$ 57,348,483.52**

Option	Percentage of Dredging Cost	Cost per Year	Cost of Operational Readiness (per year)
1	130%	$ 2,479,397.46	$ 567,781.34
2	144%	$ 2,747,584.44	$ 835,968.33
3	100%	$ 1,911,616.12	-

All costs presented are in present value dollars

7. ENVIRONMENTAL CONCERNS

7.1 Preferred Alternative for Mayport Basin

There are three possible concepts to maintain the basin depth at Mayport. The first concept is to use an alternate silt removal system to transport sediment away from the basin. The second concept is to combine an alternate sediment removal system with a more efficient maintenance dredging arrangement. The third concept is to continue to conduct periodic dredging operations. Of the three concepts, using alternate silt removal systems would impact the environment the least. The process scours the bottom next to the piers, moves fluidized mud in amounts close to ambient levels back out into the river current where it originated. Conventional dredging only impacts the environment during actual operations. However, the process includes plume generation, bottom cutting, and offshore disposal in significant amounts. Altering the flow pattern by constructing a channel to deliver stabilizing make-up water has been studied, but without further testing it is not an advisable option. The following discussion concentrates on how using TSUs and a Bernoulli pumping system to provide continuous sediment control would be viewed under current environmental regulations.

7.2 Environmental Regulations

The Environmental Protection Agency (EPA) and the United States Army Corps of Engineers are authorized by the Federal Waters Pollution Act, Section 404 to manage the coastal waters of the United States. With respect to dredging projects, this legislation requires permits be approved by the Corps of Engineers and EPA prior to conducting work that would discharge waste or fill into United States waters. The size of the

entrainment plumes caused by operating the array depends on the frequency that the system is used; more frequent cycles would result in smaller plumes. Testing operations conducted on WID projects, and fixed array systems showed that a minimal plume is generated by the use of such equipment. TSU usage has also shown that plume generation is minimal, this is especially true since the area being scoured has a low residence time (after every cycle the bottom is free from sediment). The attractive feature of using scouring equipment is that only the sediment entering the control volume since the last scouring cycle is cleared – there should be no change in water clarity. The same argument can be made for pumping sediment out of a collection pit and back into the main river flow – the sediment came from the river within the last one or two tidal cycles in the same amount, there should be no net difference in river water quality. In this regard, the permit should proceed through the approval process without difficulty.

Handling the sediment discharge from the pipeline is similar to the effluent from wasterwater treatment plants because of the plume. However because of the sediment load, the permitting process would be handled in the same way offshore dredging spoils disposal is approved. Calculations on acceptable loading rates would have to be conducted, but the annual predicted 600,000 cubic yards is less that the currently approved disposal amount of 2 million cubic yards at the Jacksonville Ocean Dredged Material Disposal Site.

7.3 Contaminated sediment issues.

Discharges from ships, flaking paint, spills, wind carried particles from other parts of the Naval Station can end up settling with the flocculated particles. The U.S. Navy has been a strong supporter of the National Environmental Protection Act, Water Quality Section in disposing waste material in coastal waters. However, prior to the legislation overboard dumping was a common practice. PPB Environmental Laboratories and McGinnes Laboratories tested the samples from past dredging upland disposals collected by Law Engineering for chemical properties, specifically levels of heavy metal and pesticide contaminants. The results indicate that the spoil areas are not contaminated, at least not through the top 20 feet of the disposal site. The dredge spoils at the upland disposal sites were placed during time periods with less stringent environmental regulations. Since the tested samples reported negative on heavy metal and pesticide contamination, it is a conservation assumption that current sediment is also free of contaminants. More specific, non-composite testing of the disposal sites and the harbor bottom would have to be conducted to support the hypothesis that the basin sediment is under contaminant threshold limits, but considering the frequency of dredging, the past allowance of ocean disposal (which undergoes testing on live organisms), and the assumption that currents do move in the basin, it is reasonable to assume that the sediment can be released into the river current without creating a contaminant problem. The premise that the sediment originates from the river and that the anti-siltation systems are removing low residence time material would also support the low contamination level assumption.

7.4 Effect on flora/fauna.

There are several species of plant and animal that use the benthic environment, directly (living in or on the bottom) and indirectly (food source) in the basin. Among these are crustaceans (bluecrab, stonecrab, grass shrimp), fish (bluefish, mullet, flounder, drum, redfish, grouper, toadfish, triggerfish), mollusks (oysters, mussels, limpets), cnidarians (moon jellyfish, mushroom jellyfish) and several species of seaweed. There are also a few animals present in the area that are on the endangered species list. These include the West Indian Manatee, Ridley's Sea Turtle, the Right Whale and the Least Tern. The Right Whale should not be directly affected by the anti-siltation system – these animals only pass through the area on their migration to feeding grounds in the North Atlantic. The Least Terns are dependent on the estuary for food and nest in several areas around the Naval Station, notably the upland dredging spoils disposal area. Impacts to the Least Tern from this project would also be minimum. The West Indian Manatee has been sighted inside Mayport Basin, feeding on seaweed beds and resting in shallow areas. The effect that the anti-siltation system has on the manatee is unknown, but could translate into reduced food production within the basin and possible harm in the immediate area where the TSUs and the jet pump arrays are operating. Although Ridley's Sea Turtle only approaches the shoreline to lay egg clutches, the same effects within the influence zone are possible. One method to prevent injury by the jet pumps would be to place a cage around the intake to prevent fish and other wildlife from being sucked into the intake. The cage would prevent larger animals from being drawn too close, yet would not hamper the intake of sediment laden water.

The current induced by the Turbo Scouring Units and the suction/discharge of the jet sump system will change the characteristics of the basin bottom. The areas scoured by the TSUs will have a flat profile with little marine growth. The scouring will remove sediment that benthic animals use for food, and during the cycle the current generated will have sufficient energy to displace most of the animals themselves. The intake systems can be outfitted with fish screens, as described above, to prevent harming larger animals. The operation would have no impacts greater than those already caused during bi-annual dredging operations and the trend would be to minimize the degree of the impacts that do take place. Unless a storm or drought changes the flow of water supplying the sediment, the process of scouring and removing sediment should be predictable and stable, compared to dredging an area after a two-year period, which would displace animals and flora that have established themselves.

7.5 Loss of Habitat.

Use of the alternative dredging system would provide a more stable, longer-term environment when compared to the effects of conventional dredging. Although the bottom areas will be scoured frequently, the resulting bottom conditions will be present for as long as the TSUs and the submersible pumps are in use. The actual sediment load would be the total 2 year sediment load divided by the number of cycles the TSU/submersible pump system goes through in two years. Conventional dredging restructures the bottom every two years and places an impulse sediment load on the disposal site. Over time the gradual loading would have less impact on the overall environment than conventional dredging.

8. CONCLUSIONS AND RECOMMENDATIONS

The results of this study show that the installation of an anti-siltation system is technologically and environmentally feasible. The technology to implement such a system currently exists and is in use at several locations across Europe and Australia, and is increasing in the United States. The cost of operating a system composed of alternate sediment removal systems, under the assumptions made in this study, is currently more expensive than conducting maintenance dredging on a bi-annual basis. For the case of Mayport Naval Station, the heavy sedimentation rate and operational requirements necessitate maintenance dredging of approximately 1.25 million cubic yards every two years. Conducting bi-annual maintenance dredging was shown to be the least expensive option. Using a system with turbo scouring units to keep the pierside area fully operational, and a catchment basin inside the harbor to lengthen the period between maintenance dredging cycles was shown to cost 44% more than conventional maintenance dredging. An alternate sediment removal system that fully eliminates maintenance dredging was shown to cost 30% more than maintenance dredging alone. The benefit of complete pierside availability for operational readiness and reduced environmental impact adds merit to these options.

The impact that maintenance dredging has on the environment is limited to a relatively short period during the operation and for a time period after, but the degree that conventional dredging has on the benthic areas is significant. A scouring system also has an impact on the environment, but the degree is similar in magnitude to the natural

sedimentation rate, limiting the effects of turbidity. This benefit is difficult to quantify, thus weighting the results of this study in favor of options that include dredging.

This study was based on several assumptions. The results could vary if the assumptions prove to be incorrect. Additional environmental studies should be conducted to verify the assumptions and to provide specific values to help design the pumps and spatial arrangements. The need for armor protecting the main discharge pipe should be evaluated. If armor is required, the cost could become prohibitive and option 2 would emerge as the best overall option.

A recommended procedure for analyzing basins for potential outfitting with alternate sediment removal systems is as follows.

- Current patterns and velocities. Establish by deploying S-4 sensors at depth and using drogues to monitor the activity during ebb and flood tides.
- Sediment sources. Take water samples from various depths along the water column to determine where the sediment load is concentrated. Correlate this information with the current patterns to provide insight into where efforts should be concentrated (addressing the source of the sedimentation problem, or at least identifying it).
- Sediment characteristics. Take samples of bottom sediments to determine the particle size distribution. Take core samples to see what the layering activity is (consolidation, settling), and examine in-situ samples to determine the degree of flocculation.
- Allow sufficient time to study the basin characteristics, with at least one pre/post storm comparison of depths at selected points to see what effects (volumetric and spatial) the storms have on the basin.

- Identify areas prone to sedimentation. Critical areas that need to be kept clear (channels, berths, turning basins, etc.) should be identified so they are not overlooked. The cost to install a system could be reduced if the coverage requirement is not as great.
- Economic analysis comparing costs to continue maintenance dredging versus installation of an alternate sediment removal system.
- Examine and assess the environmental impacts.

The alternative systems are each design to suit a specific set of environmental conditions. In all cases, a downstream elevation gradient or the presence of a current is required to transport the fluidized material away from the site to prevent redeposition. Where these conditions do not meet the optimum design parameters, a system could be installed to keep the berthing areas at the design depths, with the intent to use conventional dredging in a larger settling area. This would reduce the time to dredge and costs since the area would be easier to access.

Environmental conditions should determine the applicability of alternate dredging systems in a given site. The life cycle economics and the impacts to the environment are questions that need to be answered by the community, and are factors in determining if an alternative system should be used instead of conventional dredging.

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APPENDIX A – Large Print Drawings of Alternate Sediment Removal System Option Drawings

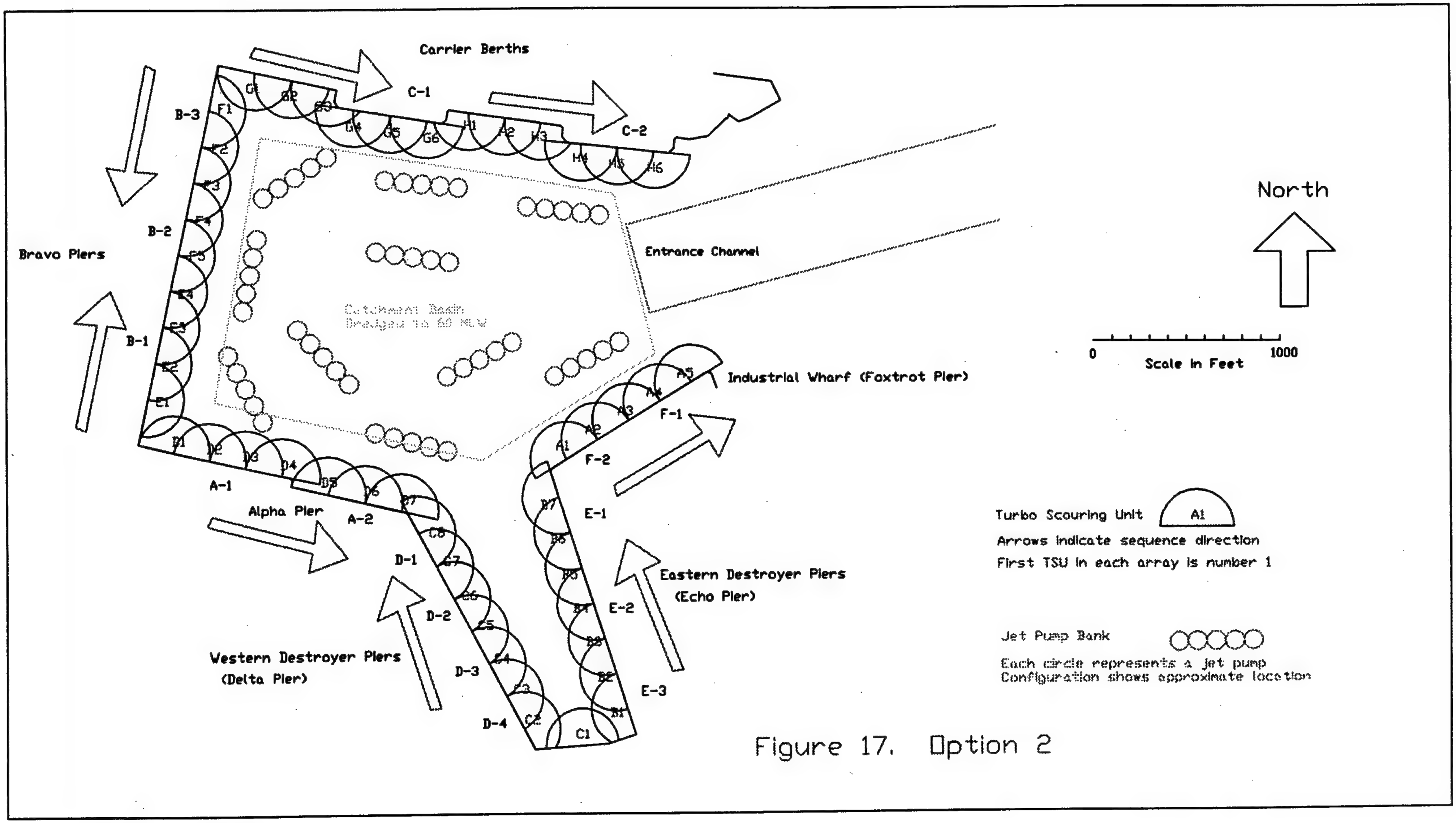

Figure 17. Option 2

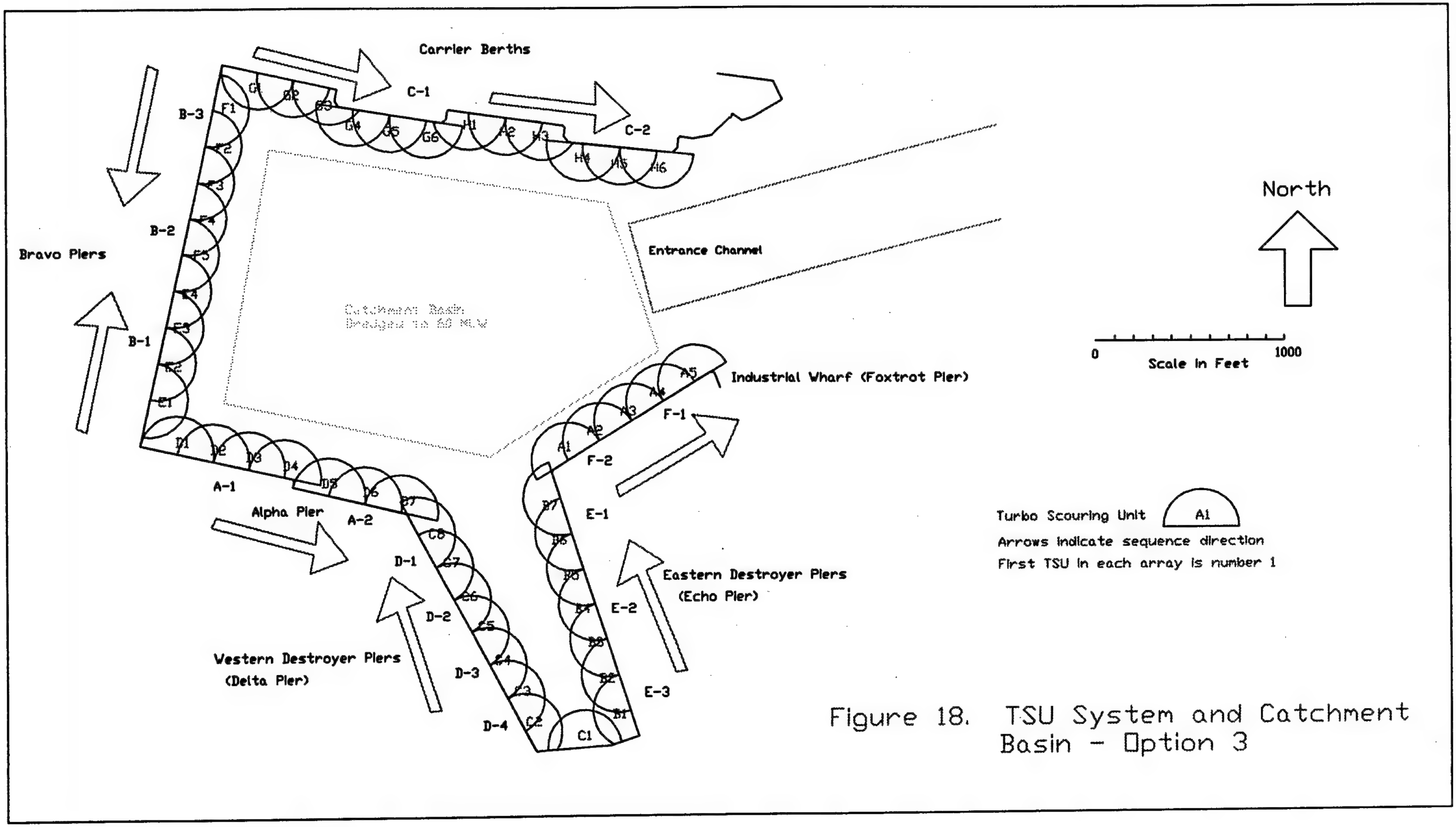

Figure 18. TSU System and Catchment Basin - Option 3

APPENDIX B – Pipe Diameter Considerations

Discharge Calculations

Intake velocity	2.3	ft/sec	
Discharge diameter	42	inches	
Flow Output from TSU	165.438	gal/sec	
No. of TSUs	48		
Time each TSU is in operation	3600	sec	
Total water displaced (per cycle)	28587680	gal	
No. of hours per cycle	6	hr	
Water displaced per hour	4764613	gal/hr	
	23590.08	cy/hr	20" pipe required
	18034.06	m^3/hr	

Capacity of Jet Pump (cy/hr)	500	1000	1500
Required No. of Jet Pumps	47	24	16
Discharge Pressure			

Using several smaller jet pumps would provide lower suction, greater area coverage as opposed to using fewer, higher capacity, larger pumps.

Other options that could be explored:
Siphoning TSU intake water from upriver - similar to channel concept - negates basin recirculation issue

APPENDIX C – Present Value of Past Dredging Costs

Mayport Dredging Cycles from 1954 to 1999

					Adjustment						
					54	55	56	57	58	59	60
Year	Quantity	Cost	Dredge	Cost/CY	-0.74	0.37	2.99	2.9	1.76	1.73	1.36
54	346312	$ 106,225.00	Hopper	$ 0.31	$ 0.31	$ 0.31	$ 0.32	$ 0.33	$ 0.33	$ 0.34	$ 0.34
56	897777	$ 241,502.00	Hydraulic	$ 0.27			$ 0.27	$ 0.28	$ 0.28	$ 0.29	$ 0.29
59	1411640	$ 258,554.00	Hopper	$ 0.18						$ 0.18	$ 0.19
59	8992	$ 11,641.00	Hydraulic	$ 1.29						$ 1.29	$ 1.31
61	1363070	$ 297,824.00	Hydraulic	$ 0.22							
61	10280	$ 9,658.00	Hopper	$ 0.94							
62	559092	$ 140,180.00	Hopper	$ 0.25							
64	289050	$ 152,040.00	Hydraulic	$ 0.53							
65	1962067	$ 545,954.00	Hydraulic	$ 0.28							
66	868479	$ 482,473.00	Hydraulic	$ 0.56							
69	716858	$ 240,187.00	Hopper	$ 0.34							
69	441323	$ 513,505.00	Hydraulic	$ 1.16							
72	570972	$ 735,651.00	Hopper	$ 1.29							
74	547565	$ 475,810.00	Hopper	$ 0.87							
75	736084	$ 943,285.00	Hydraulic	$ 1.28							
78	1789701	$ 2,523,904.00	Clam Shell	$ 1.41							
78	173558	$ 214,863.00	Hopper	$ 1.24							
79	47148	$ 161,875.00	Hopper	$ 3.43							
82	1793031	$ 4,410,000.00	Hydraulic	$ 2.46							
83	81363	$ 284,341.00	Hopper	$ 3.49							
83	48000	$ 283,500.00	Hopper	$ 5.91							
84	1200000	$ 3,059,500.00	Hopper	$ 2.55							
87	1200000	$ 3,010,500.00	Hydraulic	$ 2.55							
89	733000	$ 3,371,000.00		$ 4.60							
91	1200000	$ 2,968,000.00		$ 2.47							
93	1100000	$ 2,510,000.00		$ 2.28							
97	1024000	$ 2,100,000.00		$ 2.05							
99	1255234	$ 4,900,000.00		$ 3.90							

61	62	63	64	65	66	67	68	69	70	71	72	73
0.67	1.33	1.64	0.97	1.92	3.46	3.04	4.72	6.2	5.57	3.27	3.41	8.71
$ 0.34	$ 0.35	$ 0.35	$ 0.36	$ 0.37	$ 0.38	$ 0.39	$ 0.41	$ 0.43	$ 0.46	$ 0.47	$ 0.49	$ 0.53
$ 0.29	$ 0.30	$ 0.30	$ 0.30	$ 0.31	$ 0.32	$ 0.33	$ 0.35	$ 0.37	$ 0.39	$ 0.40	$ 0.41	$ 0.45
$ 0.19	$ 0.19	$ 0.19	$ 0.19	$ 0.20	$ 0.20	$ 0.21	$ 0.22	$ 0.23	$ 0.25	$ 0.26	$ 0.26	$ 0.29
$ 1.32	$ 1.34	$ 1.36	$ 1.37	$ 1.40	$ 1.45	$ 1.49	$ 1.56	$ 1.66	$ 1.75	$ 1.81	$ 1.87	$ 2.03
$ 0.22	$ 0.22	$ 0.23	$ 0.23	$ 0.23	$ 0.24	$ 0.25	$ 0.26	$ 0.27	$ 0.29	$ 0.30	$ 0.31	$ 0.34
$ 0.94	$ 0.95	$ 0.97	$ 0.98	$ 1.00	$ 1.03	$ 1.06	$ 1.11	$ 1.18	$ 1.25	$ 1.29	$ 1.33	$ 1.45
	$ 0.25	$ 0.25	$ 0.26	$ 0.26	$ 0.27	$ 0.28	$ 0.29	$ 0.31	$ 0.33	$ 0.34	$ 0.35	$ 0.38
			$ 0.53	$ 0.54	$ 0.55	$ 0.57	$ 0.60	$ 0.64	$ 0.67	$ 0.69	$ 0.72	$ 0.78
				$ 0.28	$ 0.29	$ 0.30	$ 0.31	$ 0.33	$ 0.35	$ 0.36	$ 0.37	$ 0.40
					$ 0.56	$ 0.57	$ 0.60	$ 0.64	$ 0.67	$ 0.69	$ 0.72	$ 0.78
								$ 0.34	$ 0.35	$ 0.37	$ 0.38	$ 0.41
								$ 1.16	$ 1.23	$ 1.27	$ 1.31	$ 1.43
											$ 1.29	$ 1.40

74	75	76	77	78	79	80	81	82	83	84	85	86
12.34	6.94	4.86	6.7	9.02	13.29	12.52	8.92	3.83	3.79	3.95	3.8	1.1
$ 0.60	$ 0.64	$ 0.67	$ 0.71	$ 0.78	$ 0.88	$ 0.99	$ 1.08	$ 1.12	$ 1.16	$ 1.21	$ 1.26	$ 1.27
$ 0.51	$ 0.54	$ 0.57	$ 0.61	$ 0.66	$ 0.75	$ 0.84	$ 0.92	$ 0.95	$ 0.99	$ 1.03	$ 1.07	$ 1.08
$ 0.32	$ 0.35	$ 0.36	$ 0.39	$ 0.42	$ 0.48	$ 0.54	$ 0.59	$ 0.61	$ 0.63	$ 0.66	$ 0.68	$ 0.69
$ 2.29	$ 2.44	$ 2.56	$ 2.73	$ 2.98	$ 3.38	$ 3.80	$ 4.14	$ 4.30	$ 4.46	$ 4.64	$ 4.81	$ 4.87
$ 0.38	$ 0.40	$ 0.42	$ 0.45	$ 0.49	$ 0.56	$ 0.63	$ 0.68	$ 0.71	$ 0.74	$ 0.77	$ 0.80	$ 0.80
$ 1.63	$ 1.74	$ 1.82	$ 1.94	$ 2.12	$ 2.40	$ 2.70	$ 2.94	$ 3.06	$ 3.17	$ 3.30	$ 3.42	$ 3.46
$ 0.43	$ 0.46	$ 0.48	$ 0.51	$ 0.56	$ 0.63	$ 0.71	$ 0.78	$ 0.81	$ 0.84	$ 0.87	$ 0.90	$ 0.91
$ 0.88	$ 0.94	$ 0.98	$ 1.05	$ 1.14	$ 1.29	$ 1.46	$ 1.58	$ 1.65	$ 1.71	$ 1.78	$ 1.84	$ 1.86
$ 0.45	$ 0.49	$ 0.51	$ 0.54	$ 0.59	$ 0.67	$ 0.76	$ 0.82	$ 0.85	$ 0.89	$ 0.92	$ 0.96	$ 0.97
$ 0.88	$ 0.94	$ 0.98	$ 1.05	$ 1.14	$ 1.30	$ 1.46	$ 1.59	$ 1.65	$ 1.71	$ 1.78	$ 1.85	$ 1.87
$ 0.46	$ 0.49	$ 0.52	$ 0.55	$ 0.60	$ 0.68	$ 0.77	$ 0.84	$ 0.87	$ 0.90	$ 0.94	$ 0.97	$ 0.98
$ 1.60	$ 1.71	$ 1.80	$ 1.92	$ 2.09	$ 2.37	$ 2.66	$ 2.90	$ 3.01	$ 3.13	$ 3.25	$ 3.37	$ 3.41
$ 1.57	$ 1.68	$ 1.76	$ 1.88	$ 2.05	$ 2.33	$ 2.62	$ 2.85	$ 2.96	$ 3.07	$ 3.19	$ 3.31	$ 3.35
$ 0.87	$ 0.93	$ 0.97	$ 1.04	$ 1.13	$ 1.28	$ 1.44	$ 1.57	$ 1.63	$ 1.70	$ 1.76	$ 1.83	$ 1.85
	$ 1.28	$ 1.34	$ 1.43	$ 1.56	$ 1.77	$ 1.99	$ 2.17	$ 2.25	$ 2.34	$ 2.43	$ 2.52	$ 2.55
				$ 1.41	$ 1.60	$ 1.80	$ 1.96	$ 2.03	$ 2.11	$ 2.19	$ 2.28	$ 2.30
				$ 1.24	$ 1.40	$ 1.58	$ 1.72	$ 1.78	$ 1.85	$ 1.93	$ 2.00	$ 2.02
					$ 3.43	$ 3.86	$ 4.21	$ 4.37	$ 4.53	$ 4.71	$ 4.89	$ 4.95
								$ 2.46	$ 2.55	$ 2.65	$ 2.75	$ 2.78
									$ 3.49	$ 3.63	$ 3.77	$ 3.81
									$ 5.91	$ 6.14	$ 6.37	$ 6.44
										$ 2.55	$ 2.65	$ 2.68

87	88	89	90	91	92	93	94	95	96	97	98
4.43	4.42	4.65	6.11	3.06	2.9	2.75	2.67	2.54	3.32	1.7	1.61
$ 1.33	$ 1.38	$ 1.45	$ 1.54	$ 1.58	$ 1.63	$ 1.68	$ 1.72	$ 1.76	$ 1.82	$ 1.85	$ 1.88
$ 1.12	$ 1.17	$ 1.23	$ 1.30	$ 1.34	$ 1.38	$ 1.42	$ 1.46	$ 1.50	$ 1.55	$ 1.57	$ 1.60
$ 0.72	$ 0.75	$ 0.79	$ 0.83	$ 0.86	$ 0.88	$ 0.91	$ 0.93	$ 0.96	$ 0.99	$ 1.00	$ 1.02
$ 5.08	$ 5.31	$ 5.55	$ 5.89	$ 6.07	$ 6.25	$ 6.42	$ 6.59	$ 6.76	$ 6.98	$ 7.10	$ 7.22
$ 0.84	$ 0.88	$ 0.92	$ 0.97	$ 1.00	$ 1.03	$ 1.06	$ 1.09	$ 1.12	$ 1.16	$ 1.17	$ 1.19
$ 3.61	$ 3.77	$ 3.95	$ 4.19	$ 4.32	$ 4.44	$ 4.57	$ 4.69	$ 4.81	$ 4.97	$ 5.05	$ 5.13
$ 0.95	$ 0.99	$ 1.04	$ 1.10	$ 1.14	$ 1.17	$ 1.20	$ 1.23	$ 1.27	$ 1.31	$ 1.33	$ 1.35
$ 1.95	$ 2.03	$ 2.13	$ 2.26	$ 2.33	$ 2.39	$ 2.46	$ 2.52	$ 2.59	$ 2.67	$ 2.72	$ 2.76
$ 1.01	$ 1.05	$ 1.10	$ 1.17	$ 1.21	$ 1.24	$ 1.28	$ 1.31	$ 1.34	$ 1.39	$ 1.41	$ 1.43
$ 1.95	$ 2.04	$ 2.13	$ 2.26	$ 2.33	$ 2.40	$ 2.46	$ 2.53	$ 2.59	$ 2.68	$ 2.72	$ 2.77
$ 1.03	$ 1.07	$ 1.12	$ 1.19	$ 1.23	$ 1.26	$ 1.30	$ 1.33	$ 1.36	$ 1.41	$ 1.43	$ 1.46
$ 3.56	$ 3.72	$ 3.89	$ 4.13	$ 4.26	$ 4.38	$ 4.50	$ 4.62	$ 4.74	$ 4.90	$ 4.98	$ 5.06
$ 3.50	$ 3.65	$ 3.82	$ 4.06	$ 4.18	$ 4.30	$ 4.42	$ 4.54	$ 4.65	$ 4.81	$ 4.89	$ 4.97
$ 1.93	$ 2.02	$ 2.11	$ 2.24	$ 2.31	$ 2.38	$ 2.44	$ 2.51	$ 2.57	$ 2.66	$ 2.70	$ 2.74
$ 2.66	$ 2.78	$ 2.91	$ 3.09	$ 3.18	$ 3.28	$ 3.37	$ 3.46	$ 3.54	$ 3.66	$ 3.72	$ 3.78
$ 2.40	$ 2.51	$ 2.63	$ 2.79	$ 2.87	$ 2.96	$ 3.04	$ 3.12	$ 3.20	$ 3.30	$ 3.36	$ 3.41
$ 2.11	$ 2.20	$ 2.31	$ 2.45	$ 2.52	$ 2.59	$ 2.67	$ 2.74	$ 2.81	$ 2.90	$ 2.95	$ 3.00
$ 5.17	$ 5.39	$ 5.64	$ 5.99	$ 6.17	$ 6.35	$ 6.53	$ 6.70	$ 6.87	$ 7.10	$ 7.22	$ 7.34
$ 2.91	$ 3.04	$ 3.18	$ 3.37	$ 3.48	$ 3.58	$ 3.67	$ 3.77	$ 3.87	$ 4.00	$ 4.06	$ 4.13
$ 3.98	$ 4.16	$ 4.35	$ 4.62	$ 4.76	$ 4.90	$ 5.03	$ 5.16	$ 5.30	$ 5.47	$ 5.56	$ 5.65
$ 6.73	$ 7.03	$ 7.35	$ 7.80	$ 8.04	$ 8.27	$ 8.50	$ 8.73	$ 8.95	$ 9.25	$ 9.40	$ 9.56
$ 2.79	$ 2.92	$ 3.05	$ 3.24	$ 3.34	$ 3.44	$ 3.53	$ 3.62	$ 3.72	$ 3.84	$ 3.91	$ 3.97
$ 2.55	$ 2.66	$ 2.79	$ 2.96	$ 3.05	$ 3.14	$ 3.22	$ 3.31	$ 3.39	$ 3.50	$ 3.56	$ 3.62
		$ 4.60	$ 4.88	$ 5.03	$ 5.18	$ 5.32	$ 5.46	$ 5.60	$ 5.78	$ 5.88	$ 5.98
				$ 2.47	$ 2.55	$ 2.62	$ 2.68	$ 2.75	$ 2.84	$ 2.89	$ 2.94
						$ 2.28	$ 2.34	$ 2.40	$ 2.48	$ 2.52	$ 2.56
										$ 2.05	$ 2.08

	Summary Table					
99	Year	Quantity	Past Cost	Past	Present	Present
2.68			Cost	Cost/CY	Cost	Cost/CY
$ 1.93	54	346312	$ 106,225.00	$ 0.31	$ 669,513.49	$ 1.93
$ 1.64	56	897777	$ 241,502.00	$ 0.27	$ 1,472,496.74	$ 1.64
$ 1.05	59	1411640	$ 258,554.00	$ 0.18	$ 1,479,937.43	$ 1.05
$ 7.41	59	8992	$ 11,641.00	$ 1.29	$ 66,631.93	$ 7.41
$ 1.23	61	1363070	$ 297,824.00	$ 0.22	$ 1,670,648.62	$ 1.23
$ 5.27	61	10280	$ 9,658.00	$ 0.94	$ 54,176.71	$ 5.27
$ 1.39	62	559092	$ 140,180.00	$ 0.25	$ 776,020.93	$ 1.39
$ 2.84	64	289050	$ 152,040.00	$ 0.53	$ 820,140.44	$ 2.84
$ 1.47	65	1962067	$ 545,954.00	$ 0.28	$ 2,889,528.65	$ 1.47
$ 2.84	66	868479	$ 482,473.00	$ 0.56	$ 2,468,149.68	$ 2.84
$ 1.50	69	716858	$ 240,187.00	$ 0.34	$ 1,072,230.05	$ 1.50
$ 5.19	69	441323	$ 513,505.00	$ 1.16	$ 2,292,361.76	$ 5.19
$ 5.10	72	570972	$ 735,651.00	$ 1.29	$ 2,912,950.28	$ 5.10
$ 2.82	74	547565	$ 475,810.00	$ 0.87	$ 1,542,733.43	$ 2.82
$ 3.89	75	736084	$ 943,285.00	$ 1.28	$ 2,859,960.76	$ 3.89
$ 3.51	78	1789701	$ 2,523,904.00	$ 1.41	$ 6,273,494.59	$ 3.51
$ 3.08	78	173558	$ 214,863.00	$ 1.24	$ 534,070.18	$ 3.08
$ 7.53	79	47148	$ 161,875.00	$ 3.43	$ 355,160.70	$ 7.53
$ 4.24	82	1793031	$ 4,410,000.00	$ 2.46	$ 7,603,674.17	$ 4.24
$ 5.81	83	81363	$ 284,341.00	$ 3.49	$ 472,355.40	$ 5.81
$ 9.81	83	48000	$ 283,500.00	$ 5.91	$ 470,958.31	$ 9.81
$ 4.07	84	1200000	$ 3,059,500.00	$ 2.55	$ 4,889,397.67	$ 4.07
$ 3.72	87	1200000	$ 3,010,500.00	$ 2.55	$ 4,461,506.95	$ 3.72
$ 6.14	89	733000	$ 3,371,000.00	$ 4.60	$ 4,498,491.95	$ 6.14
$ 3.02	91	1200000	$ 2,968,000.00	$ 2.47	$ 3,621,809.79	$ 3.02
$ 2.63	93	1100000	$ 2,510,000.00	$ 2.28	$ 2,896,931.72	$ 2.63
$ 2.14	97	1024000	$ 2,100,000.00	$ 2.05	$ 2,190,996.11	$ 2.14
$ 3.90	99	1255234	$ 4,900,000.00	$ 3.90	$ 4,900,000.00	$ 3.90
$ 3.76	Average					
2.15742041	Std Deviation					
$ 9.81	Maximum					
$ 1.05	Minimum					

APPENDIX D – Capital, Operations and Maintenance Costs

Alternative System Cost Estimate

TSU Location	Length		Jet Pumps	Cost	Quantity	Units	Total
Carrier Pier			Jet pump	$ 7,000.00	50	each	$ 350,000.00
Space prior to C-1	639.5	$ 639,472.00	Supply lines	$ 10.00	15000	lf	$ 150,000.00
	63.2		Supply pump	$ 10,000.00	6	each	$ 60,000.00
	39.5		Pump house	$ 25,000.00	4	each	$ 100,000.00
Charlie 1	560.5	$ 560,524.00					
	31.6		Polyethylene line	$ 44.00	20000	lf	$ 880,000.00
	47.4		Excavation	$ 13.00	2500	cy	$ 32,500.00
	7.9		Trenching (land)	$ 22.00	6000	lf	$ 132,000.00
Space between docks	623.7	$ 623,680.00	Trenching (underwater)	$ 50.00	12000	lf	$ 600,000.00
	15.8						
	47.4		Concrete footings	$ 300.00	60	each	$ 18,000.00
	40.0						
Charlie 2	560.5	$ 560,529.00			**Total**		**$ 2,322,500.00**
	39.5						
	47.4		**Capital Dredging**				
Destroyer Slips				Cost	Quantity	Units	Total
Foxtrot Pier	994.7	$ 994,734.00					
Bend to Eastern	15.8		Mobilization and			each	$ 50,000.00
Eastern Destroyer Slips	1484.2	$ 1,484,206.00	demobilization				
Bend 1	157.9	$ 157,894.00	Quantity	$ 7.10	970500	cy	$ 6,890,550.00
Bend 2	402.6	$ 402,630.00					
Western Destroyer Slips	1452.6	$ 1,452,627.00			**Total**		**$ 6,940,550.00**
	631.6	$ 631,577.00					
	31.6						
	15.8						
	844.7	$ 844,734.60					
	2100.0	$ 2,099,994.00					
Total	10895.2	**$ 10,452,601.60**					
			Project Total				**$ 19,715,651.60**
			w/o Jet Pumps				**$ 17,393,151.60**

Operational Costs

42" TSU			
No. of Supply Pumps		8	ea
Time per cycle		6	hr
No. of cycles per year		730	cycles
Annual total hours		35040	hr
Required pump power		75	hp
Annual Power Consumption		2628000	hp*hr
		1959699.6	kW*hr
Cost per kW*hr	$	0.14	
Annual electrical cost	$	274,357.94	
Jet Pump System			
No. of supply pumps in use		6	ea
Time per cycle		8	hr
No. of cycles per year		730	cycles
Annual total hours		35040	hr
Required pump power		450	hp
Annual Power Consumption		15768000	hp*hr
		11758197.6	kW*hr
Cost per kW*hr	$	0.14	
Annual electrical cost	$	1,646,147.66	
Operator (non-maintenance)		2000	hr
Payroll	$	30.00	
No. of operators		4	
Total employee cost	$	240,000.00	
TSU portion of labor	$	136,800.00	
Total Annual Operations	$	2,160,505.61	
TSU Only Annual Operations	$	411,157.94	

Maintenance Costs

		Diver	Technician	Operator	Cost	Time Scale
		$ 45.00	$ 40.00	$ 30.00		(annual)
TSU						
Weekly						
	Hydraulic fluid level			4	$ 120.00	$ 6,240.00
	Hydraulic fluid color			4	$ 120.00	$ 6,240.00
	Oil filter			4	$ 120.00	$ 6,240.00
	Hydraulic fluid filter			4	$ 120.00	$ 6,240.00
Quarterly						
	Raise TSU and clean with high pressure water nozzle			96	$ 2,880.00	$ 11,520.00
	Visually inspect TSU for corrosion (lifting/support cables, hydraulic fittings and zinc anodes)			48	$ 1,440.00	$ 5,760.00
	Intake system cleaned with high pressure water nozzle (biofouling)			24	$ 720.00	$ 2,880.00
	Intake grating cleaned of accumulated debris			24	$ 720.00	$ 2,880.00
	Replace zinc anodes			48	$ 1,440.00	$ 5,760.00
	Hydraulic motor and rotary actuator checked for proper operation			48	$ 1,440.00	$ 5,760.00
Annual						
	Disassemble TSU and checked for damage, check/replace interior impellor hub zinc anodes		384		$ 15,360.00	$ 15,360.00
	Check/replace drive hub zinc anodes		192		$ 7,680.00	$ 7,680.00
	Hydraulic hose fittings inside the drive hub should be checked/repaired/replaced		96		$ 3,840.00	$ 3,840.00
					Total	**$ 86,400.00**
Jet Pump						
Weekly						
	Hydraulic fluid level on supply pumps			3	$ 90.00	$ 4,680.00
	Hydraulic fluid color in supply pump reservoirs			3	$ 90.00	$ 4,680.00
	Check the oil filter on supply pumps			3	$ 90.00	$ 4,680.00
	Hydraulic fluid filter			3	$ 90.00	$ 4,680.00
	Check supply pumps for operation within manufacturer specified range			3	$ 90.00	$ 4,680.00
Quarterly						
	Raise jet pump and clean with high pressure water nozzle	200		50	$ 10,500.00	$ 42,000.00
	Visually inspect jet pump for corrosion (lifting/support cables, hydraulic fittings and zinc anodes)			50	$ 1,500.00	$ 6,000.00
	Intake system cleaned with high pressure water nozzle (biofouling)			50	$ 1,500.00	$ 6,000.00
	Intake grating cleaned of accumulated debris			100	$ 3,000.00	$ 12,000.00
	Replace zinc anodes on the jet pumps			50	$ 1,500.00	$ 6,000.00
	Check supply/discharge hoses for wear	200		100	$ 12,000.00	$ 48,000.00
	Check supply pumps for corrosion			6	$ 180.00	$ 720.00
	Replace the oil filter on the supply pumps			6	$ 180.00	$ 720.00
	Inspect the connections and fittings from the supply pump to the supply lines	50			$ 2,250.00	$ 9,000.00
Annual						
	Take the supply pumps off-line to inspect internal components for wear and damage	200	200		$ 17,000.00	$ 17,000.00
	Replace the internal zinc anodes in the supply pumps		24		$ 960.00	$ 960.00
					Total	**$ 171,800.00**
					Total	**$ 258,200.00**

APPENDIX E – Option Costs

Operation	Maintenance	Option 1 - Complete Alternate Sedimentation Removal System				
			Future Costs		Present Value	
Operation	Maintenance	Year	Operation	Maintenance	Operation	Maintenance
$2,160,505.61	$ 258,200.00	1	$ 2,160,505.61	$ 268,528.00	$ 2,038,212.84	$ 253,328.30
$2,160,505.61	$ 258,200.00	2	$ 2,336,802.87	$ 279,269.12	$ 2,079,746.23	$ 248,548.52
$2,160,505.61	$ 258,200.00	3	$ 2,430,274.98	$ 290,439.88	$ 2,040,505.74	$ 243,858.93
$2,160,505.61	$ 258,200.00	4	$ 2,527,485.98	$ 302,057.48	$ 2,002,005.63	$ 239,257.82
$2,160,505.61	$ 258,200.00	5	$ 2,628,585.42	$ 314,139.78	$ 1,964,231.94	$ 234,743.52
$2,160,505.61	$ 258,200.00	6	$ 2,733,728.84	$ 326,705.37	$ 1,927,170.96	$ 230,314.39
$2,160,505.61	$ 258,200.00	7	$ 2,843,077.99	$ 339,773.59	$ 1,890,809.24	$ 225,968.84
$2,160,505.61	$ 258,200.00	8	$ 2,956,801.11	$ 353,364.53	$ 1,855,133.60	$ 221,705.28
$2,160,505.61	$ 258,200.00	9	$ 3,075,073.16	$ 367,499.11	$ 1,820,131.08	$ 217,522.16
$2,160,505.61	$ 258,200.00	10	$ 3,198,076.08	$ 382,199.07	$ 1,785,788.98	$ 213,417.97
$2,160,505.61	$ 258,200.00	11	$ 3,325,999.13	$ 397,487.04	$ 1,752,094.85	$ 209,391.21
$2,160,505.61	$ 258,200.00	12	$ 3,459,039.09	$ 413,386.52	$ 1,719,036.46	$ 205,440.44
$2,160,505.61	$ 258,200.00	13	$ 3,597,400.65	$ 429,921.98	$ 1,686,601.81	$ 201,564.20
$2,160,505.61	$ 258,200.00	14	$ 3,741,296.68	$ 447,118.86	$ 1,654,779.13	$ 197,761.10
$2,160,505.61	$ 258,200.00	15	$ 3,890,948.55	$ 465,003.61	$ 1,623,556.88	$ 194,029.76
$2,160,505.61	$ 258,200.00	16	$ 4,046,586.49	$ 483,603.76	$ 1,592,923.73	$ 190,368.82
$2,160,505.61	$ 258,200.00	17	$ 4,208,449.95	$ 502,947.91	$ 1,562,868.57	$ 186,776.96
$2,160,505.61	$ 258,200.00	18	$ 4,376,787.95	$ 523,065.82	$ 1,533,380.48	$ 183,252.86
$2,160,505.61	$ 258,200.00	19	$ 4,551,859.46	$ 543,988.46	$ 1,504,448.77	$ 179,795.26
$2,160,505.61	$ 258,200.00	20	$ 4,733,933.84	$ 565,748.00	$ 1,476,062.95	$ 176,402.90
$2,160,505.61	$ 258,200.00	21	$ 4,923,291.20	$ 588,377.92	$ 1,448,212.70	$ 173,074.54
$2,160,505.61	$ 258,200.00	22	$ 5,120,222.84	$ 611,913.03	$ 1,420,887.94	$ 169,808.99
$2,160,505.61	$ 258,200.00	23	$ 5,325,031.76	$ 636,389.55	$ 1,394,078.73	$ 166,605.04
$2,160,505.61	$ 258,200.00	24	$ 5,538,033.03	$ 661,845.14	$ 1,367,775.36	$ 163,461.55
$2,160,505.61	$ 258,200.00	25	$ 5,759,554.35	$ 688,318.94	$ 1,341,968.28	$ 160,377.37
$2,160,505.61	$ 258,200.00	26	$ 5,989,936.52	$ 715,851.70	$ 1,316,648.12	$ 157,351.38
$2,160,505.61	$ 258,200.00	27	$ 6,229,533.98	$ 744,485.77	$ 1,291,805.70	$ 154,382.49
$2,160,505.61	$ 258,200.00	28	$ 6,478,715.34	$ 774,265.20	$ 1,267,432.01	$ 151,469.61
$2,160,505.61	$ 258,200.00	29	$ 6,737,863.96	$ 805,235.80	$ 1,243,518.20	$ 148,611.69
$2,160,505.61	$ 258,200.00	30	$ 7,007,378.52	$ 837,445.24	$ 1,220,055.59	$ 145,807.70
			$ 125,932,275.33	$15,060,376.16		

	Annual Cost	Total Present Value	
Operation	$ 2,160,505.61	$ 48,821,872.49	
Maintenance	$ 258,200.00	$ 5,844,399.61	
Capital Expense		$ 19,715,651.60	
Total for Option 1		**$ 74,381,923.70**	

Operation	Maintenance	Year	Option 1 - Complete Alternate Sedimentation Removal System: Future Costs Operation	Future Costs Maintenance	Present Value Operation	Present Value Maintenance
$2,160,505.61	$ 258,200.00	1	$ 2,160,505.61	$ 268,528.00	$ 2,038,212.84	$ 253,328.30
$2,160,505.61	$ 258,200.00	2	$ 2,336,802.87	$ 279,269.12	$ 2,079,746.23	$ 248,548.52
$2,160,505.61	$ 258,200.00	3	$ 2,430,274.98	$ 290,439.88	$ 2,040,505.74	$ 243,858.93
$2,160,505.61	$ 258,200.00	4	$ 2,527,485.98	$ 302,057.48	$ 2,002,005.63	$ 239,257.82
$2,160,505.61	$ 258,200.00	5	$ 2,628,585.42	$ 314,139.78	$ 1,964,231.94	$ 234,743.52
$2,160,505.61	$ 258,200.00	6	$ 2,733,728.84	$ 326,705.37	$ 1,927,170.96	$ 230,314.39
$2,160,505.61	$ 258,200.00	7	$ 2,843,077.99	$ 339,773.59	$ 1,890,809.24	$ 225,968.84
$2,160,505.61	$ 258,200.00	8	$ 2,956,801.11	$ 353,364.53	$ 1,855,133.60	$ 221,705.28
$2,160,505.61	$ 258,200.00	9	$ 3,075,073.16	$ 367,499.11	$ 1,820,131.08	$ 217,522.16
$2,160,505.61	$ 258,200.00	10	$ 3,198,076.08	$ 382,199.07	$ 1,785,788.98	$ 213,417.97
$2,160,505.61	$ 258,200.00	11	$ 3,325,999.13	$ 397,487.04	$ 1,752,094.85	$ 209,391.21
$2,160,505.61	$ 258,200.00	12	$ 3,459,039.09	$ 413,386.52	$ 1,719,036.46	$ 205,440.44
$2,160,505.61	$ 258,200.00	13	$ 3,597,400.65	$ 429,921.98	$ 1,686,601.81	$ 201,564.20
$2,160,505.61	$ 258,200.00	14	$ 3,741,296.68	$ 447,118.86	$ 1,654,779.13	$ 197,761.10
$2,160,505.61	$ 258,200.00	15	$ 3,890,948.55	$ 465,003.61	$ 1,623,556.88	$ 194,029.76
$2,160,505.61	$ 258,200.00	16	$ 4,046,586.49	$ 483,603.76	$ 1,592,923.73	$ 190,368.82
$2,160,505.61	$ 258,200.00	17	$ 4,208,449.95	$ 502,947.91	$ 1,562,868.57	$ 186,776.96
$2,160,505.61	$ 258,200.00	18	$ 4,376,787.95	$ 523,065.82	$ 1,533,380.48	$ 183,252.86
$2,160,505.61	$ 258,200.00	19	$ 4,551,859.46	$ 543,988.46	$ 1,504,448.77	$ 179,795.26
$2,160,505.61	$ 258,200.00	20	$ 4,733,933.84	$ 565,748.00	$ 1,476,062.95	$ 176,402.90
$2,160,505.61	$ 258,200.00	21	$ 4,923,291.20	$ 588,377.92	$ 1,448,212.70	$ 173,074.54
$2,160,505.61	$ 258,200.00	22	$ 5,120,222.84	$ 611,913.03	$ 1,420,887.94	$ 169,808.99
$2,160,505.61	$ 258,200.00	23	$ 5,325,031.76	$ 636,389.55	$ 1,394,078.73	$ 166,605.04
$2,160,505.61	$ 258,200.00	24	$ 5,538,033.03	$ 661,845.14	$ 1,367,775.36	$ 163,461.55
$2,160,505.61	$ 258,200.00	25	$ 5,759,554.35	$ 688,318.94	$ 1,341,968.28	$ 160,377.37
$2,160,505.61	$ 258,200.00	26	$ 5,989,936.52	$ 715,851.70	$ 1,316,648.12	$ 157,351.38
$2,160,505.61	$ 258,200.00	27	$ 6,229,533.98	$ 744,485.77	$ 1,291,805.70	$ 154,382.49
$2,160,505.61	$ 258,200.00	28	$ 6,478,715.34	$ 774,265.20	$ 1,267,432.01	$ 151,469.61
$2,160,505.61	$ 258,200.00	29	$ 6,737,863.96	$ 805,235.80	$ 1,243,518.20	$ 148,611.69
$2,160,505.61	$ 258,200.00	30	$ 7,007,378.52	$ 837,445.24	$ 1,220,055.59	$ 145,807.70
			$ 125,932,275.33	$15,060,376.16		

	Annual Cost	Total Present Value	
Operation	$ 2,160,505.61	$ 48,821,872.49	
Maintenance	$ 258,200.00	$ 5,844,399.61	
Capital Expense		$ 19,715,651.60	
Total for Option 1		**$ 74,381,923.70**	

Operation	Maintenance	Year	Future Costs Operation	Future Costs Maintenance	Present Value Operation	Present Value Maintenance
		Option 2 - TSU and Catchment Basin with Scheduled Dredging				
$ 411,157.94	$86,400.00	1	$ 427,604.26	$ 89,856.00	$ 403,400.25	$ 84,769.81
$ 411,157.94	$86,400.00	2	$ 444,708.43	$ 93,450.24	$ 395,788.92	$ 83,170.38
$ 411,157.94	$86,400.00	3	$ 462,496.77	$ 97,188.25	$ 388,321.21	$ 81,601.13
$ 411,157.94	$86,400.00	4	$ 480,996.64	$ 101,075.78	$ 380,994.39	$ 80,061.48
$ 411,157.94	$86,400.00	5	$ 500,236.51	$ 105,118.81	$ 373,805.82	$ 78,550.89
$ 411,157.94	$86,400.00	6	$ 520,245.97	$ 109,323.56	$ 366,752.88	$ 77,068.80
$ 411,157.94	$86,400.00	7	$ 541,055.80	$ 113,696.51	$ 359,833.01	$ 75,614.67
$ 411,157.94	$86,400.00	8	$ 562,698.04	$ 118,244.37	$ 353,043.71	$ 74,187.98
$ 411,157.94	$86,400.00	9	$ 585,205.96	$ 122,974.14	$ 346,382.51	$ 72,788.20
$ 411,157.94	$86,400.00	10	$ 608,614.20	$ 127,893.11	$ 339,846.99	$ 71,414.84
$ 411,157.94	$86,400.00	11	$ 632,958.76	$ 133,008.83	$ 333,434.78	$ 70,067.39
$ 411,157.94	$86,400.00	12	$ 658,277.12	$ 138,329.18	$ 327,143.56	$ 68,745.37
$ 411,157.94	$86,400.00	13	$ 684,608.20	$ 143,862.35	$ 320,971.04	$ 67,448.28
$ 411,157.94	$86,400.00	14	$ 711,992.53	$ 149,616.85	$ 314,914.98	$ 66,175.67
$ 411,157.94	$86,400.00	15	$ 740,472.23	$ 155,601.52	$ 308,973.19	$ 64,927.08
$ 411,157.94	$86,400.00	16	$ 770,091.12	$ 161,825.58	$ 303,143.51	$ 63,702.04
$ 411,157.94	$86,400.00	17	$ 800,894.76	$ 168,298.60	$ 297,423.82	$ 62,500.11
$ 411,157.94	$86,400.00	18	$ 832,930.55	$ 175,030.55	$ 291,812.05	$ 61,320.87
$ 411,157.94	$86,400.00	19	$ 866,247.78	$ 182,031.77	$ 286,306.16	$ 60,163.87
$ 411,157.94	$86,400.00	20	$ 900,897.69	$ 189,313.04	$ 280,904.16	$ 59,028.70
$ 411,157.94	$86,400.00	21	$ 936,933.59	$ 196,885.56	$ 275,604.08	$ 57,914.95
$ 411,157.94	$86,400.00	22	$ 974,410.94	$ 204,760.98	$ 270,404.00	$ 56,822.22
$ 411,157.94	$86,400.00	23	$ 1,013,387.38	$ 212,951.42	$ 265,302.04	$ 55,750.10
$ 411,157.94	$86,400.00	24	$ 1,053,922.87	$ 221,469.48	$ 260,296.34	$ 54,698.21
$ 411,157.94	$86,400.00	25	$ 1,096,079.79	$ 230,328.26	$ 255,385.09	$ 53,666.17
$ 411,157.94	$86,400.00	26	$ 1,139,922.98	$ 239,541.39	$ 250,566.50	$ 52,653.60
$ 411,157.94	$86,400.00	27	$ 1,185,519.90	$ 249,123.04	$ 245,838.83	$ 51,660.14
$ 411,157.94	$86,400.00	28	$ 1,232,940.69	$ 259,087.97	$ 241,200.36	$ 50,685.42
$ 411,157.94	$86,400.00	29	$ 1,282,258.32	$ 269,451.49	$ 236,649.41	$ 49,729.09
$ 411,157.94	$86,400.00	30	$ 1,333,548.65	$ 280,229.54	$ 232,184.33	$ 48,790.80
			$23,982,158.40	$5,039,568.17		

	Quantity (cy)	Unit Cost	Cyclic Cost	Total Present Value
Operation			$ 411,157.94	$ 9,306,627.91
Maintenance			$ 86,400.00	$ 1,955,678.26
Capital Expense				$ 17,393,151.60
Maintenance Dredging	1713691	$ 3.76	$ 6,443,476.28	$ 53,772,075.50
Total for Option 2				**$ 82,427,533.27**

Option 2 - Maintenance Dredging			
Quantity (cu yd)	Cost/cy	Cost	
1713691	$ 3.76	$ 6,443,476.28	
	Future Costs Adjusted for 4% Inflation	Present Value Considering 6% Cost of Money	
Present 1-year	$ 6,443,476.28	$ 6,078,751.21	
Cycle 1 (year 3)	$ 7,248,034.50	$ 6,085,589.53	3
Cycle 2 (year 6)	$ 8,153,053.08	$ 5,747,580.71	6
Cycle 3 (year 9)	$ 9,171,075.90	$ 5,428,345.74	9
Cycle 4 (year 12)	$10,316,213.12	$ 5,126,841.87	12
Cycle 5 (year 15)	$11,604,336.76	$ 4,842,084.28	15
Cycle 6 (year 18)	$13,053,300.66	$ 4,573,142.84	18
Cycle 7 (year 21)	$14,683,188.00	$ 4,319,139.08	21
Cycle 8 (year 24)	$16,516,589.58	$ 4,079,243.32	24
Cycle 9 (year 27)	$18,578,917.03	$ 3,852,671.97	27
Cycle 10 (year 30)	$20,898,754.92	$ 3,638,684.96	30
Total 30 year cost		**$ 53,772,075.50**	

Option 3 - Bi-Annual Dredging		
Quantity (cu yd)	Cost/cy	Cost
1255000	$ 3.76	$ 4,718,800.00
	Future Costs Adjusted for 4% Inflation	Present Value Considering 6% Cost of Money
Present 1-year	$ 4,718,800.00	$ 4,451,698.11
Cycle 1 (year 2)	$ 5,103,854.08	$ 4,542,411.96
Cycle 2 (year 4)	$ 5,520,328.57	$ 4,372,617.28
Cycle 3 (year 6)	$ 5,970,787.38	$ 4,209,169.50
Cycle 4 (year 8)	$ 6,458,003.64	$ 4,051,831.37
Cycle 5 (year 10)	$ 6,984,976.73	$ 3,900,374.52
Cycle 6 (year 12)	$ 7,554,950.83	$ 3,754,579.11
Cycle 7 (year 14)	$ 8,171,434.82	$ 3,614,233.50
Cycle 8 (year 16)	$ 8,838,223.90	$ 3,479,133.99
Cycle 9 (year 18)	$ 9,559,422.97	$ 3,349,084.49
Cycle 10 (year 20)	$ 10,339,471.89	$ 3,223,896.21
Cycle 11 (year 22)	$ 11,183,172.79	$ 3,103,387.45
Cycle 12 (year 24)	$ 12,095,719.69	$ 2,987,383.29
Cycle 13 (year 26)	$ 13,082,730.42	$ 2,875,715.35
Cycle 14 (year 28)	$ 14,150,281.22	$ 2,768,221.54
Cycle 15 (year 30)	$ 15,304,944.17	$ 2,664,745.83
Total 30 year cost		**$ 57,348,483.52**

Summary Table

Option	Capital	Maintenance Costs	Operation Costs	Maintenance Dredging	Total Cost	Percentage of Dredging Cost	Cost per Year	Cost of Operational Readiness (per year)
1	$ 19,715,651.60	$ 5,844,399.61	$ 48,821,872.49	-	**$ 74,381,923.70**	130%	$ 2,479,397.46	$ 567,781.34
2	$ 17,393,151.60	$ 1,955,678.26	$ 9,306,627.91	$ 53,772,075.50	**$ 82,427,533.27**	144%	$ 2,747,584.44	$ 835,968.33
3	-	-	-	$ 57,348,483.52	**$ 57,348,483.52**	100%	$ 1,911,616.12	-

All costs presented are in present value dollars

Table presented in Paper Insertion format

Option	Capital	Maintenance Costs	Operation Costs	Maintenance Dredging	Total Cost
1	$ 19,715,651.60	$ 5,844,399.61	$ 48,821,872.49	-	**$ 74,381,923.70**
2	$ 17,393,151.60	$ 1,955,678.26	$ 9,306,627.91	$ 53,772,075.50	**$ 82,427,533.27**
3	-	-	-	$ 57,348,483.52	**$ 57,348,483.52**

Option	Percentage of Dredging Cost	Cost per Year	Cost of Operational Readiness (per year)
1	130%	$ 2,479,397.46	$ 567,781.34
2	144%	$ 2,747,584.44	$ 835,968.33
3	100%	$ 1,911,616.12	-

All costs presented are in present value dollars

APPENDIX F – Sediment Reduction Factor Calculation for Option 2

Scouring effect from TSU
Dredging quantity modification

MLW

Year 1

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2015495	18	36278910
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			299307620
Mixing Ratio			0.088123056

Year 2

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2015495	12	24185940
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			287214650
Mixing Ratio			0.091493939

Year 3

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2015495	6	12092970
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			275121680
Mixing Ratio			0.095132966

High Tide

	area (ft^2)	depth (ft)	volume (ft^3)
Turning Basin	5436810	4.5	24465645
Destroyer Piers	990934	4.5	4459203
Total Volume			28924848

Annual Sedimentation
16942500 ft^3

Coefficient
0.092

Adjusted Sedimentation
15390850 ft^3

Annual Available Space
12092970 ft^3

Increasing catchment
basin dimensions to
1610 x 1610 yields
appropriate amount

MLW

Year 1

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2592100	18	46657800
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			309686510
Mixing Ratio			0.085421966

Year 2

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2592100	12	31105200
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			294133910
Mixing Ratio			0.089534326

Year 3

	area (ft^2)	depth (ft)	volume (ft^3)
Catchment Basin*	2592100	6	15552600
Turning Basin	5436810	42	228346020
Destroyer Piers	990934	35	34682690
Total Volume			278581310
Mixing Ratio			0.094062663

High Tide

	area (ft^2)	depth (ft)	volume (ft^3)
Turning Basin	5436810	4.5	24465645
Destroyer Piers	990934	4.5	4459203
Total Volume			28924848

Annual Sedimentation
16942500 ft^3

Coefficient
0.090

Adjusted Sedimentation
15423215 ft^3

Annual Available Space
15552600 ft^3